Chapter 4
Sediment Quality of Broad Creek and the Okatee River

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Introduction:

Recent regional studies of southeastern estuaries have documented degraded sediment and water quality in several of the more developed drainage systems as well as in a few of the relatively undeveloped systems (e.g. NOAA, 1988; 1991; Hyland et al., 1996; Long et al., 1998). Although some of these estuaries have been sampled intensively, the majority have not and the extent of contaminant concentrations is very poorly understood in all but a few of the estuaries. Interpretation of the existing data is further confounded by the variety of sampling and analytical methods used in these studies, which makes it very difficult to evaluate the relationships between land-use patterns and estuarine habitat quality with respect to anthropogenic contaminant concentrations.

Because the southeastern region of the United States is experiencing rapid development of the coastal zone, it is imperative for scientists and coastal zone managers to (1) have adequate knowledge of the current state of our estuaries, and (2) understand the potential impacts of changes in land-use patterns on estuarine habitat quality. Several large-scale studies, such as the NOAA/EPA Environmental Monitoring and Assessment Program (EMAP) and the NOAA Status and Trends (NS&T) Program have attempted to define the condition of southeastern estuaries on a regional scale, but sampling in both of those programs is too limited to adequately assess conditions within a given drainage basin. More intensive sampling has been conducted by numerous researchers from various state, federal, academic and private institutions in many coastal areas of South Carolina and Georgia. However, these data are in different formats and the range of data quality (e.g. detection limits) is quite variable among the studies. Additionally, most of these data sets are not readily accessible or in a form that could easily used by scientists outside those institutions that collected the data.

Background:

Estuarine environments in South Carolina are facing significant developmental pressures which mandates that local, state and federal environmental agencies must take more proactive management of upland development to protect these important ecosystems. These *Spartina alterniflora* estuarine ecosystems are among the most productive ecosystems in the biosphere and are of particular importance in terms of their

nursery ground function for finfish and shellfish. Currently, greater than 75% of all finfish and shellfish species are estuarine dependant, using estuarine environments for one or more of their life history stages for development. The dynamic nature of these estuarine environments is matched by the dynamic nature of the life history/development stages of the many species of fish and shellfish utilizing these environments.

Coastal estuaries in South Carolina vary greatly in size, hydrography (e.g. fresh water flushing characteristics) and the amount of terrestrial upland development surrounding each watershed. The smallest estuaries are generally located in the northern third of South Carolina (north of Georgetown-Winyah Bay) and are generally high salinity systems (>35 ppt during dry weather periods), which do not have a major river flowing into each system and are diluted only by runoff from rainfall. As a result of these geographic characteristics, small high salinity estuaries are influenced by land development directly adjacent to the estuary rather than development further inland.

The largest estuaries in the state are located south of Georgetown and include Winyah Bay, Charleston Harbor, St. Helena Sound (e.g. ACE Basin), Port Royal Sound, Calibogue Sound and the Savannah River. These large estuaries have rivers which flow into the estuaries (e.g. riverine estuaries) and generally have substantial urban and industrial development in the surrounding upland terrestrial watersheds. In addition to impacts from adjoining land development within the proximate watershed, these estuaries are greatly influenced by freshwater flow from rivers within each system and resulting salinities are lower then in non-riverine, high salinity estuaries. Moreover, several of these riverine estuaries (e.g. Winyah Bay, Charleston Harbor, Port Royal Sound and the Savannah River) are ports of commerce, with extensive commercial fleets as well as recreational boating activities. Conversely, non-riverine estuaries are surrounded primarily by urban (roadways, infrastructure) and suburban (e.g. housing, service/tourism industries, and marinas) upland development and are generally lacking in industrial development, and contain marinas primarily for recreational boating.

The impact of upland development has not been well studied in South Carolina. While several state and federal monitoring programs have chronicled the levels of selected chemical contaminants at long term monitoring stations, these efforts have generally not been focused on characterizing pollution sources in upland areas in a quantitative manner. Marcus and Scott (1989) summarized data from the SCDHEC trend monitoring data on chemical contamination of sediments and biota (oysters and blue crabs) in 16 estuaries with varying degrees of urban development. Polycyclic aromatic hydrocarbons (PAHs) were the contaminants chosen for study, since they are indicative of urban activities associated with fossil fuel combustion. Results indicated that a significant increase in total PAH sediment concentrations was observed in association with increased amounts of urbanization. Concomitant increased uptake of PAHs was observed in oysters and blue crabs, which was associated with urban runoff. Large metropolitan urban complexes, such as Charleston Harbor and Winyah Bay, had the highest PAH concentrations in sediments and biota measured, whereas small high salinity estuaries, such as North Inlet, a NOAA National Estuarine Research Reserve and Sanctuary (NERRS) site, had the lowest PAH concentrations measured. Also, suburban

areas such as in Beaufort County were generally found to have low to moderate PAH concentrations.

PAH pollution may adversely affect living marine resources of estuaries by severely (e.g. acute toxicity) or chronically (e.g. sublethal affects on growth, development and reproduction) affecting resident fauna. Although some estuarine organisms possess methods for detoxifying PAHs by making them water soluble and then excreting the altered chemicals, these processes require energy and therefore are not without metabolic cost to the organisms such as decreased or altered growth, development and reproduction. Decreased reproductive potential may be directly related to "ecological death", since reduced offspring production may ultimately affect population size and structure within a given species and may alter food chain trophic structure for dependent species. Other contaminants associated with urban development such as PCBs, persistent pesticides (e.g. chlordane = termiticide), and trace metals (e.g. Cu = bottom fouling paint in boats) are also of a significant concern.

More recent studies (Fulton et al., 1993; Vernberg et al., 1993; Sanders,1995; Fortner et al., 1996) have attempted to derive more quantitative relationships between land-use and coastal development on estuarine ecosystem health. The Urbanization in Southeast Estuaries (Eco) System (USES) study has studied the effects of coastal development on Murrells Inlet, an estuary highly developed for tourism, and North Inlet, a pristine, undeveloped estuary which is a NOAA NERRS site. The goal of the USES Project was to establish a Geographical Information System (GIS) based land-use model which is linked with fishery based population models to identify urban, nonpoint source (NPS) loading regions within estuaries and to measure resulting effects on living marine resources of commercial, recreational and ecological importance.

Results of the USES Project indicated that significant NPS runoff loading of PAHs and coliform bacteria occurred in watersheds adjacent to terrestrial upland areas. Major sources of PAHs included runoff from parking lots and roadways, and discharges from marinas, while major sources of coliform bacteria appeared to be related to remaining septic tanks within the estuary. Bacteriological "fingerprinting" of coliform positive bacteria clearly indicated that *E. coli* bacteria (e.g. an indicator of human and other mammalian species) densities and prevalence rates were much higher in urbanized Murrells Inlet and that estuarine regions free of coliform bacteria occurred at a rate 6 times higher in pristine North Inlet. Similarly, the highest PAH concentrations in sediments and oysters were found adjacent to transportation corridors and marinas. Highest coliform bacterial densities were found adjacent to areas of significant suburbanization (e.g. residential housing and service industries) and co-occurred with the highest levels of PAHs at frequencies higher than would be predicted from random, chance occurrence. This suggests that coliform bacteria may significantly interact with PAHs, and that fecal coliform bacteria may degrade PAHs in sediments, possibly using the carbon-hydrogen source of the PAHs as a energy source. Marcus and Scott (1989) reported that in laboratory bioassays, fecal coliform bacteria were able to use low concentrations of PAHs as an energy source. Finley et al. (1999) further reported that reduced abundances and altered reproductive output in grass shrimp in Murrells Inlet

were significantly correlated with increased sediment PAH concentrations along with alterations in salinity and dissolved oxygen levels.

Another important study that provided insight and background on the effects of upland urbanization in estuarine habitats was the Tidal Creek Study conducted by the South Carolina Department of Natural Resources. Small headwater tidal creeks within each river system of the Charleston Harbor estuary were studied and compared with the larger river/harbor regions of the estuary in terms of benthic and pelagic community structure, chemical contaminant loading, toxicological screening, and physicochemical water quality. Major findings of this study include the following: 1) Greatest chemical contaminant loadings occur in the headwater areas of tidal creeks and major pollution sources from urbanization include PAHs, chlordane and some trace metals; 2) Industrial Point source pollution is an additive input to the urban NPS runoff loading pulse; 3) PAH concentrations, which were the dominant urban pollutant found in Murrells Inlet in the USES study, are greatly increased in regions receiving additional industrial discharges; 4) Some industrial discharges have caused pollution of both tidal creek as well as river reaches of Charleston Harbor; 5) Altered physicochemical water quality, in particular alterations in dissolved oxygen and salinity dynamics, occurred in developed watersheds; 6) Grass shrimp abundances were significantly reduced in some urban, suburban, and industrial, and agricultural watersheds; 7) Generally, benthic and pelagic community structures were not altered in comparisons of developed and undeveloped watersheds; and 8) Reduced immune function was observed in mummichogs (*Fundulus heteroclitus*) in developed watersheds. Results from the Tidal Creek project may enable scientists to better discern impacts from coastal development on complex riverine estuaries and have prompted GIS models to be developed which may elucidate interactive effects from multiple stressors, such as percent impervious surface area within each watershed.

Study Objectives:

Results from the USES and Tidal Creek Projects have greatly added to our knowledge of the impacts of urbanization and coastal development. Knowledge of the spatial distributions and effects of chemical contaminants within different watersheds needs further study and synthesis of data in order to better link the effects of land development on the environment. Nowhere is the need more critical than in Beaufort County, South Carolina where population doubling times are around 25 years. In particular, highly develop watersheds such as Broad Creek near Hilton Head, SC, have not been adequately characterized in terms of chemical contaminants. Additionally, rural watersheds which will be rapidly developed in the next 10 years, such as the Okatee River, have not been studied at all.

The objective of this study was to develop sediment contaminants and toxicology baselines for highly developed (Broad Creek) and rural (Okatee River) watersheds in Beaufort County. Specific sub-objectives included:

1) Assessment of the physical sediment characteristics in Broad Creek and the Okatee River including grain size and Total Organic Carbon (TOC);

2) Assessment and comparisons of sediment contaminant concentrations of trace metals, PAHs, pesticides and PCBs in Broad Creek and the Okatee River;

3) Comparisons of measured sediment concentrations of chemical contaminants with Sediment Quality Guidelines;

4) Evaluation of toxicological responses in biota to sediment bound contaminants using a variety of sediment bioassays, and

5) Development of contaminant databases to be used in formulating effective risk reduction strategies for managing chemical contaminant risks from urban NPS runoff.

Bottom Sediment Composition:

Sediment composition was evaluated at each tidal creek, subtidal river, and intertidal river site (Figures 4.1 and 4.2) to provide the physical information needed for interpretation of biological and contaminants data. The distribution of macrobenthic infaunal organisms is directly influenced by sediment type. Feeding and respiratory behaviors of many of these animals are adapted to specific sediment conditions. Consequently, a grain size description of the mixture of sand to silt-clay (mud) is essential to understanding the types of invertebrate communities that are present within a habitat. Total organic carbon (TOC) is derived from both natural and anthropogenic sources. The natural decomposition of vegetation such as salt marsh cord grass represents an abundant source of TOC. Organic carbon is a vital component of the salt marsh ecosystem and serves as a primary source in the food chain. Man-made influences can also contribute to TOC values. Increased surface water run-off from upland development activity can elevate TOC values and lead to organic enrichment.

Both grain size and TOC content can be correlated with the accumulation of contaminants. Fine sediment particles and organic matter bond with contaminants and serve as traps that concentrate pollutants. Since organic material serves as a food source to estuarine biota it also increases the likelihood of consumption or bioavailability of toxic compounds.

Methods:

Sediment composition samples were collected in conjunction with all benthic infaunal samples. See Chapter 5 for a detailed description of field collection methods. A 3.5-cm x 15-cm deep core sample was extracted from each grab sample in the intertidal and subtidal stations or directly adjacent to each biological core in the tidal creeks.

Replicate sediment composition samples for each site were combined to provide one homogeneous composite sample. To supplement benthic interpretations of tidal creek data, sediment composition samples were collected both as replicates and composites.

In the laboratory, sediment composition samples were analyzed for grain size (% sand, % silt-clay) and TOC (Table 4.1). Grain size analyses consisted of using a modification of the pipette method described by Plumb (1981). TOC was determined by using a modification of methods described by Hyland et al. (1998).

Sediment data were analyzed by various parametric and non-parametric statistical measures as appropriate. Grain size descriptions for each site are based on the inverse relationship between sand and silt-clay (mud). Statistical analyses were performed on the percent occurrence of sand.

Findings:

Subtidal Stations*:*

Grain size and TOC in surficial sediments collected at the subtidal stations of Broad Creek were not significantly different ($p = 0.59$, Mann-Whitney Rank Sum Test and $p = 0.39$, Mann-Whitney Rank Sum Test, respectively) from those collected in the Okatee River (Table 4.2, Figure 4.3). Subtidal sediments from both basins were high in sand content. Broad and Okatee stations both averaged over 90% sand (Table 4.2).

TOC values were also similar between systems ranging from 0.05% to 0.64% (Table 4.2). These are low to normal TOC values for estuarine systems in the Southeast and are not indicative of organic enrichment (Summers et al., 1993). No distributional gradient for sand content or TOC was apparent in either system.

Intertidal Stations:

Intertidal stations were considerably muddier and more variable than the subtidal stations (Figure 4.3). Percent sand values ranged from 5.8% to 68.6%. As with the subtidal sediment, no significant difference was found in sand ($p = 0.712$, t-test) or TOC ($p = 0.742$, t-test) content of intertidal sediment between Broad Creek and the Okatee River.

Intertidal sites were the muddiest and contained the highest TOC values of the three habitats. This is characteristic of intertidal shoals and results from the sheltered nature of this area which produces a reduced flushing. Most TOC values were near or above the 2% level used by Summers et al. (1993) to delineate organic enrichment (Table 4.2). However, data presented by Summers et al.(1993) was derived from a subtidal sampling effort. Higher TOC values can be expected from intertidal and tidal creek habitats due to their proximity to upland and salt marsh sources of organic carbon.

Tidal Creek Stations:

The composite samples collected from the tidal creeks were similar in sand and TOC content to the intertidal sites. Sand values were again variable ranging from 10.7% to 85.9 % (Table 4.2). The occurrence of sand in tidal creeks from the two drainage systems was significantly different for non-composited ($p<0.001$, t-test) samples. The large difference in grain size between the two T6 creeks accounted for most of the overall statistical difference between the two watersheds (Figure 4.3). Pair-wise multiple comparisons of creeks 1 through 5 showed no other significant differences. Tidal creeks in the Broad Creek were approximately 24% sandier overall than those in the Okatee River (Table 4.3).

TOC values from the tidal creeks were not significantly different between the two estuaries ($p = 0.132$, Mann-Whitney Rank Sum Test). The range in TOC from 0.53% to 3.10% was typical of that found by Lerberg (1997) and Sanger (1998) regardless of associated upland land-use (i.e. forest versus urban). Tidal creeks exhibited differences within each system; however, no gradients in the distribution of sand and TOC content existed from lower to upper estuary in either system. Similarly, no patterns were clear along the lengths of the tidal creeks (Table 4.2). TOC values were positively correlated with increased silt-clay content ($p<0.001$, $r^2 = 0.803$) throughout the study area**.**

In summary, sediment grain size was coarser in all tidal creeks and several (2/3) intertidal sites in Broad Creek. Coarser sandier sediments are generally more indicative of erosion of terrigenous sediments associated with increased urbanization. At river sites, both Broad Creek and the Okatee River were sand dominated sediments. TOC was generally equivalent in inter-site comparisons among different microhabitats within each system. Generally, higher TOCs were observed in intertidal sites and some of the tidal creek habitats than in subtidal stations. The fact that sediment TOCs in Broad Creek were not increased when compared to the Okatee River suggests that increased water column TOCs must be enriched in dissolved rather than particulate carbon.

Sediment Contaminants:

Estuarine sediments are repositories for chemicals discharged from land or atmospheric deposition. In sediments, chemical contaminants may bind with carbon in the sediments, adsorb to sediment particles and become dissolved in sediment porewater. Accumulations of chemical contaminants in sediments may result in significant exposure to benthic and epibenthic fauna as compounds may be bioaccumulated by marine organisms and become toxic. Compounds which are persistent, resist biodegradation and are highly lipophilic have the greatest potential to accumulate in sediments, become bioaccumulated by estuarine organisms and exert toxic effects in benthic fauna. Once accumulated in benthos, these compounds may be further bioaccumulated in higher trophic levels, such as crabs, birds and fish. Sediment contaminant profiles may thus provide indications of land-based pollution such as urban and agricultural sources. Specific types of chemical contaminants include trace metals, pesticides, polycyclic

aromatic hydrocarbons (PAHs = combusted petroleum byproducts) and polychlorinated biphenyls (PCBs = electrical transformer insulating fluid).

National studies have been conducted by NOAA and the State of Florida, which have developed national and regional Sediment Quality Guidelines (SQGs) for the U.S. (Long and Markel, 1992; Long et al., 1998) and southeastern U.S. (MacDonald, 1994). These SQGs have summarized all published toxicology and biomonitoring studies for a given contaminant and ranked them from lowest to highest concentration where an adverse effect was observed. Measured sediment contaminant levels may be compared with SQGs to predict potential probability for sediment bound contaminants to cause toxicity in benthic faunal communities.

In this study, selected trace metals, pesticides, PAHs and PCBs concentrations (Table 4.1) were determined in tidal creek, subtidal river, and intertidal river sediments from Broad Creek (n=15 sites; Figure 4.2) and the Okatee River (n= 15 sites; Figure 4.3) using methods as described in the section below.

Methods:

Sediment Sample Collection:

At each site the sampling vessel was piloted to pre-selected station coordinates (latitude and longitude) by use of Global Positioning Systems. At each site where sediments samples were collected, physicochemical water quality was measured with a Hydrolab DataSonde to obtain information on water temperature (^{o}C), pH, salinity (ppt or ‰), conductivity (umhos) and dissolved oxygen concentrations (mg of O_2/L and % saturation).

For sediments, only the upper 3-5 cm of sediment were sampled to ensure sampling of the most recently deposited materials which in turn should be reflective of the recent contaminant history for each site. Sediments were removed from the grab, composited in a stainless steel pot and then were dispensed into pre-cleaned (solvent/acid) containers. All samples were transported to the lab on ice and were stored at -70^{o}C until analysis. Each sediment sample was analyzed for trace metals (Aluminum, Silver, Arsenic, Cadmium, Chromium, Copper, Iron, Mercury, Nickel, Manganese, Lead, Selenium, Tin and Zinc); Polycyclic Aromatic Hydrocarbons (PAHs-24 priority pollutants, plus additional NOAA NS&T list compounds), pesticides (aldrin, atrazine, azinphosmethyl, chlordane and metabolites, chlorpyrifos, chlorthalonil, fenvalerate, dieldrin, DDT and metabolites, endosulfan, heptachlor and metabolites, hexachlorobenzene, lindane ,mirex, and trifluralin) and PCBs (27 PCB congeners and Total PCBs) using methods described below (Table 4.1)**.**

Organic Contaminant Extraction Procedures:

The methods for extraction and sample preparation for organic contaminants (PAHs, PCBs, chlorinated pesticides) in sediments were similar to those of Krahn et al. (1988), Sanders (1995), Fortner et al. (1996) and Kucklick et al. (1997) with a few modifications. Internal standards were added to each sample. The sample was then extracted in a Soxhlet apparatus with 250 ml of CH_2Cl_2 for 18 hours, concentrated by nitrogen blow-down (Turbo Vap, Zymark Instruments) to about 0.5 ml, and was additionally cleaned up by gel permeation chromatography to remove lipids and other high molecular weight compounds.

Polycyclic Aromatic Hydrocarbon (PAH) Analysis:

PAHs were quantified by two methods, capillary GC-ion trap mass spectrometry (ITMS) and High Performance Liquid Chromatography (HPLC) with fluorescence detection using techniques described by Sanders (1995) and Kucklick et al. (1997). Spiked matrix samples (sediments), standard reference materials (SRMs) and blanks were analyzed using both HPLC with fluorescence detection and GC-ITMS. Previous results using this method have indicated spike recovery efficiencies of > 88% (mean for all PAHs) in sediments.

Chlorinated Hydrocarbon Analysis:

Chlorine-containing compounds (organochlorine pesticides and PCBs) were similarly analyzed using gas chromatography with electron capture detection (GC-ECD; Hewlett-Packard-Packard- 5890 series II) using methods described by Kucklick et al. (1997). Both spiked sediments and NIST SRMs were analyzed for organochlorine compounds to obtain information on the reliability of the organochlorines and pesticides data collected (NIST SRM 1941). The overall recovery (mean ± standard deviation) of organochlorines from amended sediments was 102% ± 23% for PCBs and 89% ± 32% for organochlorine pesticides plus metabolites.

Trace Metals Analysis:

Trace metals were analyzed using methods described by Long et al., (1998). A suite of metals (Al, As, Cd, Cr, Cu, Fe, Pb, Mn, Ni, Sn, Zn) were analyzed by inductively coupled plasma spectroscopy (ICP). The metals Ag, As, Cd, Pb, and Se were analyzed by graphite furnace atomic absorption (Perkin Elmer 5100 Atomic Absorption Spectrometer with a Zeeman HGA 600 Graphite Furnace). Mercury was analyzed by cold-vapor atomic absorption using a Leeman Labs PS200 mercury analyzer at a wavelength of 253.7 nm. Samples for each analytical method were analyzed in duplicate and averaged. Quality control samples (blanks, spikes and SRMs for sediment) were analyzed with each group of samples for each analytical method. Previously, recoveries for these different analytical methods have averaged (mean ± standard deviation) 95% ± 25% for all trace metals by all methods. All recoveries were within the acceptable confidence limits of the SRM material.

Acid Volatile Sulfide (AVS) and Simultaneously Extractable Metals (SEM) Analysis:

The general procedure for measuring Acid Volatile Sulfides (AVS) and Simultaneously Extractable Metals (SEM) in sediments were based on Allen et al. (1993) with slight modifications. Spiked recoveries for AVS using this method averaged 85% ± 2.7%.

SEMs were measured in the 50.0-ml aliquot removed from each sediment extract. The acid treatment removes metals which are weakly associated with the sediments and not incorporated in crystalline matrices. Samples were analyzed by ICP for the metals (Al, As, Cd, Cr, Cu, Fe, Pb, Mn, Ni, Sn, Zn) using the methods and QA/QC procedures previously described.

Comparison of Contaminant Chemistry Data With Sediment Quality Guidelines:

Determination of the toxicological importance of sediment contaminants may be determined in three basic ways: 1) sediment toxicity tests; 2) biomonitoring of benthos and epibenthos; and 3) comparison of sediment concentrations with national and regional sediment quality guidelines (Long and Markel, 1992; MacDonald, 1993; Long et al., 1995, 1998). This sediment quality triad approach has been the cornerstone of sediment contaminant chemistry risk assessment for the past 12-15 years (Long and Chapman, 1985; Long, 1989). Most studies utilize comparisons with established sediment quality guidelines as the starting point of interpreting the toxicological potential of chemical contaminants found in sediments. For this study, we used guidelines published by Long et al. (1998) and MacDonald (1994). The primary difference between he two methods is that Long et al. (1998) combine both effects and no effects data for each chemical contaminant, while McDonald (1994) classifies data separately into effects and no effects data sets. For a single contaminant, the concentrations causing adverse effects in the identified studies are ranked from the lowest to the highest concentration causing adverse effects. The tenth percentile of this distribution represents a threshold for predicting declining environmental quality, which is termed the Effects Range Low (ERL) (Figure 4.4). The Threshold Effects Level (TEL) represents another estimate of low-level effect concentration. In this method, data are categorized into studies which measured adverse effects and studies finding no adverse effects. TELs are calculated by taking the square root of the product of the fifteenth percentile of the effects data and the fiftieth percentile of ranked no effects data. The median concentration, the fiftieth percentile of the ranked adverse effects concentrations, where all published studies found an adverse effect is a highly probable concentration for predicting declining environmental quality, which is termed the Effects Range Median (ERM) (Figure 4.4). Another measurement of median effects levels, the Probable Effects Level (PEL), is based on categorized data like TELs and is calculated by taking the square root of the product of the fiftieth percentile of the effects data and the eighty-fifth percentile of no effects data. Fulton et al. (1996) compared sediment toxicity tests with a battery of invertebrate species and screening

level toxicity tests (Microtox™ and Rototox™) and found significant agreement between the sediment quality guidelines and the most sensitive species for the three compounds tested (Cd, DDT and Flouranthene).

In addition, methods for evaluating the cumulative effects of multiple, co-occurring compounds have been developed which involve the summing of the ratios of concentrations of individual chemicals divided by their respective ERM or PEL value (Long et al., 1998; Hyland et al., 1999). The summed ratio is then divided by the number of analytes measured to calculate an "ERM/PEL Quotient" (ERM/PEL Q). Hyland et al. (1999) found that the ERM/PEL Q method was accurate in predicting degraded benthic community assemblages in estuaries throughout the southeastern U.S.

Sediment contaminant levels in Broad Creek and the Okatee River were compared with existing sediment quality guidelines by both individual compound and cumulative contaminant comparison methods. Sites with sediments which had individual chemical contaminant concentrations which exceeded ERL/TEL and ERM/PEL guideline levels were identified to indicate that trace metal, pesticide, PAH and PCB concentrations exceeded levels potentially toxic to estuarine organisms. In addition, individual contaminant levels in Broad Creek and Okatee River sediments were compared with peak sediment contaminant levels measured in the ACE Basin, a nearby pristine NOAA National Estuarine Research Reserve and Sanctuary (NERRS) site, to indicate the anthropogenic nature of these sediments. Cumulative ERM/PEL Quotients (ERM/PEL Q) were calculated for each site and sites were considered good (ERM/PEL Q $\leq$ 0.024), marginal (ERM/PEL Q > 0.024 $\leq$ 0.077) or degraded (ERM/PEL Q > 0.077).

Statistical Analysis of Data

Statistical analysis of data involved comparisons of chemical contaminant concentrations, and laboratory toxicity test (Microtox™, clams and oysters) results between habitats within a watershed (tidal versus intertidal versus river = ***Intrasite Comparisons***) and between watersheds (Broad Creek versus Okatee River = ***Intersite Comparisons***). Statistical analysis methods included the use of parametric [Analysis of Variance (ANOVA) and Multiple Comparison Tests (Dunnets)] for normally distributed data and equivalent nonparametric procedures [Kruskal Wallace (ANOVA) and Distribution Free or Dunns Multiple Comparisons] for non-normally distributed data sets which could not be normally transformed. Only differences which were significant ($p \leq 0.05$) were considered significant.

In addition linear regression and nonlinear, nonparametric (Spearman Rank Correlation) regression analysis were conducted to evaluate the relationships between different variables [contaminant chemistry results including As sediment concentrations, lindane sediment concentrations and Cumulative ERMQ]; Microtox™, clam and oyster bioassay results; and water quality results). Correlation coefficients [R (Linear Regression) and Rho (Spearman Rank Correlation)] were determined for each pair of

variables analyzed. Only regressions which were significant ($p \leq 0.05$) were considered significantly correlated.

Findings:

Chemical Contaminants Concentrations in Sediments:

Results of chemical contaminant analysis of sediments generally indicated only minor contamination of sediments in both Broad Creek and the Okatee River (Tables 4.3 - 4.7 and Figures 4.5- 4.6). The results of the contaminant analyses indicated that sediment concentrations of inorganic compounds were generally very low, within regional background concentrations for many contaminants. The only trace metal which had elevated concentrations was arsenic, which exceeded sediment quality guidelines at 9 sites, 4 in the Okatee River and 5 in Broad Creek (Table 4.3). Comparison of the maximum arsenic concentrations in Broad Creek and Okatee River (13.7-14.3 ug/g) with the ACE Basin (14.2 ug/g), a NOAA NERRS site, indicated very similar concentrations (Table 4.7). This suggests that arsenic was from a naturally occurring, background source rather than being an anthropogenic source. Sediments in the southeastern U.S. have a high regional background concentration of As, which often exceeds the ERL/PEL values. Wirth et al. (1996) found that field deployed oysters, downstream of a confined disposal site for dredged sediments, had a field derived EC_{50} for inhibition of spat settlement and condition/gonadal indices of 12.5 ppm arsenic which was very similar to the ERL value of 8.2 ppm. In the Broad Creek and Okatee River, all other trace metals (Cd, Cr, Cu, Pb, Hg, Ni, Ag and Zn) had sediment concentrations comparable to background levels observed for the ACE Basin (Table 4.7). Total trace metal concentrations (Figure 4.5) indicated that there were comparable levels of trace metals throughout Broad Creek and the Okatee River. Highest total metal concentrations were observed at intertidal and tidal sites within each estuary, with lowest concentrations observed at river stations. There were no significant differences observed in total trace metal concentrations between Broad Creek and Okatee River sediments.

PAH sediment concentrations were generally low at all sites, within regional background concentrations for most contaminants. The only PAH found at elevated concentrations was Acenaphthene at one site in Broad Creek (Intertidal Station 6). This concentration exceeded sediment quality guidelines (Table 4.4). Comparison of the maximum concentrations of individual PAHs in Broad Creek and Okatee River (2.43-93.9 ng/g in Broad Creek versus < 1.11 - 96.4 ng/g in the Okatee River) with the ACE Basin (0.50 - 88.9 ng/g) indicated very similar concentrations (Table 4.7). This suggests that most PAHs are the result of atmospheric deposition of combusted petroleum rather than nonpoint source or point source discharges. This also implies that efforts to control NPS runoff from roadways and impervious surface in Broad Creek and Okatee River have been generally successful. Previous studies of marinas in this areas (Marcus et al., 1988) had indicated generally high levels of PAHs within the main areas (e.g. fuel docks and berthing areas) of each marina studied. There was no evidence that PAHs were

transported far from marina sites. Results from this study generally support those conclusions by Marcus et al. (1988).

Total PAH concentrations (Figure 4.5) indicated that there were comparable levels of PAHs throughout Broad Creek (mean = 150.7 ± 26.5 ng/g) and the Okatee River (mean = 129.8 ± 20.9 ng/g). Highest total PAH concentrations were observed in intertidal and tidal sites within each estuary, with lowest concentrations being observed in river stations. There were no significant differences observed in sediment total PAH concentrations between Broad Creek and Okatee River.

The results of PCB analyses indicated that sediment concentrations were generally very low (0.07-0.12 ng/g), as 93.3% of the sites in each watershed had nondetectable PCB concentrations (Table 4.5). Detectable PCB concentrations were measured at only 6.7% of the sites within each watershed and measured concentrations were within regional background concentrations. The only PCBs measured were PCB congener 44 in the Okatee River and PCB congener 29 in Broad Creek (Table 4.5). Comparison of the maximum total PCB concentrations in Broad Creek (0.12 ng/g) and Okatee River (0.07 ng/g) with the ACE Basin (< 1.42 ng/g) indicated very similar concentrations (Table 4.7). This suggests that PCB pollution within each watershed is very rare and highly isolated. Total PCB concentrations (Figure 4.6) were comparable throughout Broad Creek and the Okatee River. Detectable total PCB concentrations were only observed sporadically in river and tidal creek sites within each estuary. No detectable concentrations of PCBs were measured in intertidal stations in either watershed. There were no significant differences observed in sediment total PCB concentrations between Broad Creek and Okatee River.

The results of pesticide analyses indicated that sediment concentrations of pesticides were generally very low (<detection limits - 2.78 ng/g) as 26.7% and 40% of the sites in Okatee River and Broad Creek, respectively, had no detectable concentrations (Table 4.6). Detectable pesticide concentrations were measured at 73.3% of the sites in Okatee River and 60% of the sites in Broad Creek. Pesticides measured in Okatee River sediments included lindane, heptachlor, HCB, and mirex. In Broad Creek, sediments contained detectable concentrations of aldrin, dieldrin, lindane, heptachlor and HCB. Surprisingly, no detectable levels of DDT were measured in sediments from either watershed. Generally, measured pesticide concentrations were within regional background concentrations for sediments. The only pesticides detected which were at toxicologically significant concentrations were lindane and dieldrin. Lindane was detected at 10 sites, 4 in Broad Creek and 6 in Okatee River. Elevated dieldrin concentrations were measured at only 1 site in Broad Creek (Table 4.6). Comparison of the maximum concentration for each individual pesticide in Broad Creek and Okatee River with the ACE Basin generally indicated lower or similar concentrations (Table 4.7) in Broad Creek and Okatee River when compared to the ACE Basin, with the exception of lindane and dieldrin in Broad Creek and lindane in Okatee River. This suggests that, generally, pesticide pollution for both watersheds is rare and confined to only a few sites within each watershed. In addition, higher lindane levels were measured at 2 sites (tidal creek station 1 and intertidal station 6) in Broad Creek than levels in the Okatee River,

suggesting a more contemporary urban source of lindane in Broad Creek than Okatee River. Lindane sources in Okatee River may be more historical agricultural uses of lindane. Total pesticide concentrations (Figure 4.6) were comparable throughout Broad Creek and the Okatee River. Highest total pesticide concentrations were observed in tidal creek and intertidal river sites. Lower concentrations of pesticides were measured in river stations in both watersheds. There were no significant differences observed in sediment total pesticide concentrations between Broad Creek (< DL -2.78 ng/g) and Okatee River (< DL - 2.75 ng/g).

Comparison of Contaminant Data With Sediment Quality Guidelines:

ERL/TEL exceedances were observed for arsenic, gamma BHC (lindane) and acenapthene for sites in both Broad Creek (40% of the sites) and the Okatee River (67% of the sites) (Tables 4.3-4.6). The only ERM/PEL exceedances were for lindane in Broad Creek (13.4% of the sites). In Broad Creek, sites with ERL/TEL exceedances included Tidal Creek stations T-1 (lindane) , T-4 (As) and T-5 (As); River station R-5 (lindane); and Intertidal stations I-4 (As) and I-6 (As, lindane, dieldrin and acenaphthene) which also had a PEL exceedance (lindane) (Figure 4.7). In Okatee River, ERL/TEL exceedances included Tidal Creek stations T-4 (As), and T-6 (As); River stations R-1 (lindane), R-2 (lindane), R-3 (lindane), R-5 (lindane), and R-6 (lindane); and Intertidal Stations I-2 (As), I-4 (As) and I-6 (As) (Figure 4.8). Note that the ERL/TEL exceedances for arsenic and lindane were observed in both Broad Creek and Okatee River.

Arsenic contamination was found throughout all habitat types including tidal creek, river and intertidal sites in both the Okatee River and Broad Creek. As previously mentioned, all arsenic concentrations are naturally higher in southeastern estuaries, thus elevated arsenic levels may not necessarily reflect anthropogenic pollution. It is interesting to note that 27 to 33% of sites in Broad Creek and the Okatee River had arsenic concentrations that exceeded the ERL. This is very similar to the 29.2% of sites in the ACE Basin which had arsenic concentrations that exceeded the ERL. In terms of accumulative effects, arsenic accounted for greater than 20% of the ERM/PEL Q in Broad Creek and the Okatee River, which is very similar to the 25% contribution of arsenic to the ERM/PEL Q for the ACE Basin.

Lindane contamination in Broad Creek was confined primarily to stations at the headwaters or mouth of the creek. In the Okatee River, lindane was much more pervasive, possibly due to the large amount of agricultural activity within the region. Sediment with lindane occurred throughout the entire watershed, primarily in river and intertidal stations. Multiple ERL/TEL or ERM/PEL exceedances were only observed at one site in Broad Creek (Intertidal Station 6).

The ERM/PEL Quotient (ERM/PEL Q) determinations indicated that the majority of the contaminant risks in Broad Creek and Okatee River were from arsenic and lindane exposure in sediments (Tables 4.3, 4.6, and 4.8). In Broad Creek, the majority (53.4%) of stations had good sediment quality (ERM/PEL Q $\leq$ 0.024) (Table 4.8 and Figure 4.9). The remainder of stations had marginal (33.3%) or degraded (13.3%) sediment quality.

In the Okatee River, many (40%) of the stations had good sediment quality (based on findings compiled by Hyland et al. (1999) who found that an ERM/PEL Q $\leq$ 0.024 generally corresponded with healthy benthic communities) (Figure 4.9). The remainder of stations in the Okatee River (60%) had marginal sediment quality. There were no degraded sites in the Okatee River.

Based upon the ERM/PEL Q approach in Broad Creek the following stations were classified as:

Degraded: T-1, I-6, **Marginal:** T-2, I-4, T-4, R-5, T-5.

All other Broad Creek sites were classified as good (8 sites). Toxicity would not be expected at good sites, whereas toxicity would be expected at degraded sites and a potential exists for toxicity at marginal sites.

In the Okatee River, the following sites were classified as:

Degraded: None **Marginal:** R-1, I-2, T-2, T-4, I-4, R-5, T-5, T-6, I-6

All other Okatee River sites were classified as good (6 sites). No degraded sites were observed in the Okatee River. Toxicity would not be expected at good sites, whereas toxicity would be expected at degraded sites and a potential exists for toxicity at marginal sites.

Sediment Toxicity Tests:

Sediment contaminant chemistry analyses can document the presence of contaminants, but the potential for adverse effects is not readily predictable. The bioavailability of pollutants to organisms is a dynamic component that is the result of complex physical and chemical as well as biological interactions. Laboratory toxicity tests (Microtox™, seed clam growth, bivalve fertilization, and bivalve development) were used as indicators of potential impacts on the biota and as indirect indicators of contaminant bioavailability (Figure 4.10). Ecotoxicological assessments may be conducted at different levels of biological activity, ranging in complexity from a subcellular to ecosystem level (Figure 4.10). Measurement of effects at biological levels of organization ranging from a cellular to organism level may have high toxicological relevance but low ecological relevance. Conversely, measurement of effects at biological levels of organization ranging from an organismal to ecosystem level may have high ecological relevance but low toxicological relevance. The organismal level of biological organization represents an optimum level of assessment for balancing ecological and toxicological sensitivities. Measurements of adverse effects in sediment bioassays used in this study may not translate directly into adverse toxic effects in field populations of fish and shellfish, but may serve as *early warning indicators* of ecological/toxicological stress.

The Microtox™ assay measures the change in respiration of the marine bacterium, *Vibrio fisheri*, as measured by changes in phosphorescent activity (light production). Oyster fertilization and development assays were conducted with sediment elutriates (i.e. seawater extracts of sediments). All of these assays, also based on sublethal endpoints, are potentially very sensitive to contaminants, and can be performed in a relatively short time period (i.e. a few minutes for Microtox™ assay to a few hours for the fertilization assay and 48 hours for the development assay). The clam assay is a more chronic assay. For the 7-day seed clam bioassay, growth of juvenile clams (*Mercenaria mercenaria*) was used as the endpoint, making this a sublethal assay designed to identify the potential for chronic effects. The Environmental Monitoring and Assessment Program (EMAP) for southeastern estuaries (Hyland et al., 1998) documented that the seed clam and Microtox™ assays were the most sensitive of the four methods used.

Methods:

Microtox™ (Microbial) Assay:

The Microtox™ Solid Phase bioassay was performed on whole sediment from each site using the large sample protocol described in the Microtox™ Manual (Microbics Corporation, 1992). At least seven serial dilutions of the sample and three controls were used in each assay. Triplicate assays were performed for each of the sediment samples. The EC_{50} (sediment concentration at which a 50% reduction in light production occurs) was determined for each sample after 5 minutes exposure. For those samples for which an EC_{50} was higher than the highest sediment concentration tested, the sample was designated as having an EC_{50} value greater than the highest concentration tested and was considered toxic. All EC_{50} values were corrected for moisture content using the formula in the Microtox™ Manual (Microbics Corporation, 1992) and reported on a percent dry weight sediment basis. EC_{50} values for individual replicates at each site were pooled (mean +/- standard error) and compared with regional EMAP reference values to determine if sediments at each site were potentially toxic (Ringwood et al., 1995; Hyland et al., 1998). For sediments that had $\geq$ 20% silt and clay content the toxic threshold was EC_{50} values $\leq$ 0.2% sediment (dry weight = dw), while sediments with < 20% silt and clay content had a toxic threshold of EC_{50} values $\leq$ 0.5% sediment (dw). The percentages of sites with toxic sediments in each watershed (Broad Creek and the Okatee River) were then computed based upon these EMAP toxicity threshold values.

Seed Clam 7-Day Growth Assays:

Seed clam 7-day growth assays were conducted as described by Ringwood and Keppler (1998). Briefly, juvenile clams (*Mercenaria mercenaria*) of approximately 1.0 mm in length (commonly referred to as seed clams, obtained from Atlantic Littleneck Clam Farms, Folly Beach, SC) were exposed to sediments for seven days and the effects on total dry weight were determined. On the day before initiation of an experiment, sediments were press-sieved through a 500 µm screen and approximately 50 ml were

added to 4 replicate 250 ml beakers. Control sediments (collected from Folly River, SC) were prepared in the same manner. Seawater was filtered through a 1 µm filter bag, adjusted to 25 ‰ with deionized water, and added to the replicate beakers for a total volume of 200 ml. The sediment suspension was allowed to settle overnight and clams (30 - 50 per replicate) were added the next day. Clams were size-selected prior to use with 500, 710 and 1000 µm sieves in series. Replicate subsets of clams were dried and weighed for initial weight estimates. All experiments were conducted at room temperature (23 - 25^{o}C), with gentle aeration, and all replicates were fed three times during the course of the experiment (a phytoplankton mixture composed of equal volumes of *Isochrysis galbana* and *Chaetocerus gracilis*, cultured at Marine Resources and Research Institute (MRRI) and dialyzed against filtered seawater to remove excess nutrients and other components of the culture media). Reference toxicants (cadmium) tests with clams were conducted to ensure the health of the clams used in each bioassay.

At the end of the 7-day exposure period, clams were sieved from the sediments (or water, in the case of the reference toxicant tests), placed in clean 25 ‰ seawater and allowed to depurate for approximately one hour. Clams were recaptured on a sieve, and rinsed briefly with distilled water to remove excess salt. Dead clams were removed before being processed for growth, although mortalities were less than 10%. The clams were dried overnight (60 - 70^{o}C), counted, weighed on a micro-balance, and growth rates (µg/clam/day) were determined. The effects on growth rates were statistically evaluated using a T-test or Mann-Whitney U test when variances were unequal. Sediments were defined as toxic when the mean growth rate was significantly different from the control sediment growth rate ($p < 0.05$) and < 80% of the control sediment growth rate.

Bivalve Fertilization and Development Assays:

Bivalve fertilization and development assays were conducted as described in Ringwood (1992), using sediment elutriate. Sediment (20 g) from each site were mixed with seawater (200 ml, 25 ‰) and placed on a shaker overnight. The mixtures were then filtered through 1.0 µm glass fiber filters, and three concentrations of the elutriate (100%, 50%, and 20%) as well as seawater controls were used for the assays. For all assays, there were 4 replicate tubes, each containing 10 ml of the elutriate treatments. Eggs and sperm from adult oysters (*Crassostrea virginica*) were stripped from ripe individuals, washed, and counted.

For the fertilization assays, sperm concentrations were adjusted so that the sperm to egg ratio would be 200:1 during the exposures. The sperm were incubated in the elutriate treatments for one hour, and then approximately 2000 eggs were added to each tube. After a two hour incubation period, all treatments were fixed in 10% formalin. A minimum of 200 eggs were counted from each tube, and those that were proceeding towards one or more cleavages were scored as fertilized while unfertilized eggs were scored as abnormal.

For the developmental assay, approximately 200 fertilized embryos were added to a second series of elutriate tubes and incubated for 48 hours. At the end of 48 hours, all embryos from each tube were scored as normal (i.e. development proceeded to the D-hinged larval stage) or abnormal (i.e. unshelled or abnormal shells, arrested in the early trochophore stage, etc.). The results from both assays were expressed as % controls. Treatments were defined as toxic when the mean response was <80% and statistically significantly different from the controls ($p < 0.05$). These criteria were used for both the fertilization and developmental endpoints.

Findings:

Microtox™

The results of solid phase Microtox™ testing indicated that 73% of the sites in Broad Creek and 40% of the sites in the Okatee River were potentially toxic (Table 4.9 and Figure 4.11). Nationally, NOAA has reported that 47% of all estuarine areas exhibit toxicity in the Microtox™ bioassay. Long et al. (1998) assessed the toxicity of sediment bound chemical contaminants from Winyah Bay, Charleston Harbor and Leadenwah Creek in SC and the Savannah River and Brunswick Harbor estuaries in GA. Results of the solvent extract Microtox™ assay for each estuary indicated that 70% of the sites sampled in Winyah Bay, 42.9% of Charleston Harbor, 20.1% of Leadenwah Creek, 57.1% of the Savannah River estuary and 46.4% of Brunswick Harbor were degraded sites, having significantly lower EC_{50} values than measured at reference sites or sites with minimal levels of chemical contaminants (Long et al., 1998). Similarly, Hyland et al. (1998) reported solid phase Microtox™ toxicity at 19 - 39% of estuarine areas evaluated in the southeastern U.S. (NC, SC, GA and northern FL), averaging 19% of the area, where as Long et al. (1998) reported solvent extract Microtox™ toxicity at 47.7% of estuarine area evaluated in the southeastern U.S. (SC and GA).

Statistical analysis indicated high correlations ($R^2 = 0.37$, $p \leq 0.04$) of Microtox™ bioassay results and ERM/PEL Qs for Broad Creek and Okatee River (Table 4.10). Long et al. (1998) reported similar correlations between Microtox™ bioassay results and cumulative ERM/PEL Qs for Charleston Harbor, Winyah Bay and Leadenwah Creek ($R^2 = 0.27$). Lower correlations between ERMQ and solid phase Microtox™ bioassay results were found in the Savannah River ($R^2 = 0.16$), while higher correlations were found in St. Simon Sound, GA ($R^2 = 0.61$). Hyland et al. (1998) found that in estuaries of the southeastern U.S., Microtox™ toxicity was highly correlated with sediment arsenic ($R^2 = 0.57$) concentrations but not with lindane ($R^2 = 0.12$) concentrations, which were the dominant sediment contaminants in both Broad Creek and Okatee River. Similarly, regression analysis of data from Broad Creek and the Okatee River indicated significant correlations between Microtox™ toxicity and arsenic sediment concentrations (Rho = 0.58), but not with lindane (Table 4.10).
Long et al. (1998) also reported generally high correlations ($R^2 = 0.16$-0.61) for arsenic and solvent extract Microtox™ bioassay results in SC and GA estuaries. Reported Microtox™ EC_{50} values for lindane range from 6,370 - 7,650 mg/L (Qureshi et al., 1982;

Calleja et al., 1994) versus 35 mg/L for As (Qureshi, 1982). This suggests that arsenic was 181-219 times more toxic to *Vibrio fisheri* than lindane. Elevated arsenic sediment concentrations in both Broad Creek and Okatee River were generally higher and more pervasive than lindane (As concentrations = 0.04-14.3 ug/g dw versus lindane concentrations < 0.076 - 2.43 ug/g dw). The maximum arsenic concentration was < 40% of the Microtox™ EC_{50} value measured for arsenic. The maximum lindane concentration was < 0.03% of the Microtox™ EC_{50} value measured for lindane. This would suggest that most of the toxicity may be attributed to arsenic rather than lindane, but neither compound would be the sole cause of toxicity at any given site, since none of the sites had sediment concentrations approaching the EC_{50} values for either compound. Further evidence of this is provided by regression analysis (Table 4.10) which indicated that arsenic and lindane sediment concentrations were inversely related (e.g. arsenic concentrations decreased as lindane concentrations increased or vice versa). This indicates that sources of arsenic and lindane are different (naturally occurring for arsenic versus agricultural/urban for lindane).

Water quality results for Broad Creek and Okatee River were not correlated with Microtox™ results, nor were Microtox™ results correlated with any of the other bioassays (clam or oyster) used in this study (Table 4.10). This lack of correlation between bioassay results is not surprising since each assay endpoint measured different sublethal measures of stress (respiration, growth, fertilization and development) at different taxanomic levels (bacteria, clams and oysters). Long et al. (1998) found only correlation (R^2 = 0.31-0.50) between solvent extract Microtox™ bioassay results and sea urchin fertilization and development in evaluating sediment toxicity in estuarine areas of SC and GA.

Another method to evaluate toxicity test results for each bioassay is to examine the occurrence of toxicity relative to sediment quality guidelines at each site. The concordance of toxicity and marginal/degraded sediment quality may indicate if chemical contaminants pose significant risks to living marine resources in each watershed. This was evaluated in this study by examining the occurrence of toxicity relative to sediment quality guideline results for each site. In Broad Creek, only 45.4% of the Microtox™ toxicity was observed at sites with ERL/TEL or ERM/PEL exceedances versus 57.1% in the Okatee River. Similarly, Hyland et al. (1998) reported that 73.6% of the Microtox™ toxicity measured in estuaries of SC, GA, NC and northern FL was observed at stations with high sediment contaminant levels (ERL exceedances). Further evaluation of the Microtox™ toxicity revealed that in Broad Creek, only 54.5% of the Microtox™ toxicity was observed at sites with ERM/PEL Q > 0.024 versus 85.7% in the Okatee River. This suggests that the majority of the effects on *Vibrio fisheri* respiration in the Okatee River were associated with sites with high levels of chemical contaminants. Whereas in Broad Creek, while the majority (54.5%) of sites with effects were associated with high levels of chemical contaminants, a large portion (45.5%) were associated with other effects such as increased ammonia or degraded water quality conditions although water quality was not statistically correlated with Microtox™ results.

Microtox™ toxicity was greatest in tidal creek habitats in both Broad Creek (100%) and the Okatee River (83.3%) when compared to river (Broad Creek = 50%; Okatee River = 16.7%) and intertidal (Broad Creek = 67%; Okatee River = 0%) habitats. This suggests that toxicity was greatest in sites closest to land based pollution sources (tidal creeks) and depositional environments (tidal creeks and intertidal flats).

Seed Clam Assays :

The results of juvenile clam bioassay indicated that 53% of the sites in Broad Creek and 73% of the sites in the Okatee River had inhibited clam growth (Table 4.11 and Figure 4.12). Reduced growth was observed more frequently in the tidal creek sites, but the majority of these sites had both elevated levels of porewater ammonia (> 14 mg/L) in addition to enriched concentrations of several chemical contaminants. Previous studies based on a more extensive database indicated that ammonia levels greater than 14 mg/L caused toxicity that could not be readily distinguished from contaminants (Ringwood and Keppler, 1998). Toxicity was also observed at all of the intertidal sites in the Okatee River and at two of the three intertidal sites in Broad Creek. No toxicity was observed in the majority of the subtidal sites from both systems.

Within each watershed, only a portion of observed reduced clam growth was attributed to chemical contaminants (arsenic and lindane) at both Broad Creek (33% of the sites) and Okatee River (40% of the sites). Similarly, Hyland et al. (1998) also reported reduced growth in the juvenile clam bioassay at sites representing 39% of estuarine areas evaluated in the southeastern U.S. (NC, SC, GA and northern FL). The remaining toxicity observed in each watershed was potentially attributed to high sediment porewater ammonia concentrations. Further evaluation of measured porewater ammonia concentrations found that only 20% of the sites in Broad Creek and 33% of the sites in Okatee River had reduced clam growth due to high ammonia concentrations (>14 - <30 mg/L). Ringwood and Keppler (1998) reported that ammonia concentrations of < 14 mg/L were not toxic to juvenile clams, while concentrations > 30 mg/L were toxic, with intermediate ammonia levels being potentially toxic.

Statistical analysis indicated high correlations ($R^2 = 0.51$, $p \leq 0.004$) of juvenile clam bioassay results and cumulative ERM/PEL Q for Broad Creek and Okatee River (Table 4.10). In each watershed, these represented sites with ERL/TEL and/or ERM/PEL sediment quality guideline exceedances and reduced clam growth. Hyland et al. (1998) found that in estuaries of the southeastern U.S., juvenile clam toxicity was only highly correlated with sediment porewater sulfide concentrations ($R^2 = 0.41$) but was not highly correlated with any individual sediment contaminant such as arsenic and lindane, which were the dominant sediment contaminants in both Broad Creek and Okatee River. In addition, Hyland et al. (1998) reported that clam toxicity was not statistically correlated with sediment ammonia concentrations.

Water quality results for Broad Creek and Okatee River were not correlated with juvenile clam bioassay results, nor were juvenile clam bioassay results correlated with any of the other bioassays (Microtox™ or oyster) used in this study. This lack of

correlation between bioassay results is not surprising since each assay endpoint measured different sublethal measures of stress (respiration, growth, fertilization and development) at different taxonomic levels (bacteria, clams and oysters). Long et al. (1998) found only correlation (R^2 = 0.31-0.50) between solvent extract Microtox™ bioassay results and sea urchin fertilization and development in evaluating sediment toxicity in estuarine areas of SC and GA.

In Broad Creek, just 37.5% of the juvenile clam effects were observed at sites with only ERL/TEL or ERM/PEL exceedances versus 36.4% in the Okatee River. If sites with both porewater ammonia and ERL/TEL or ERM/PEL exceedances are considered, 62.5% of the sites in Broad Creek versus 45.5% in the Okatee River had reduced growth in the clams. Similarly, Hyland et al. (1998) reported reduced juvenile clam growth in 39% of the area surveyed in NC, SC, GA and northern FL. Only 38.5% of those areas (representing 15% of the total survey area) had mortality in the juvenile clam toxicity tests measured at stations with high sediment contaminant levels (ERL exceedances). Further evaluation of the reduced juvenile clam growth revealed that in Broad Creek, only 37.5% of the juvenile clam toxicity was observed at sites with ERM/PEL Q > 0.024 versus 36.4% in the Okatee River. If sites with both ERM/PEL Q > 0.024 and with high porewater ammonia concentrations (> 14 mg/L) are considered, then 75% of the sites in Broad Creek versus 63.6% of the sites in Okatee River exhibited juvenile clam toxicity. This suggests that in Okatee River the majority of the effects on *Mercenaria mercenaria* growth were associated with sites with only high levels of chemical contaminants (36.4%) rather than sites with only high levels of porewater ammonia (18.2%). In Broad Creek, the majority of *M. mercenaria* growth inhibition was associated with sites with only high levels of chemical contaminants (37.5 %) rather than sites with only high levels of porewater ammonia (0%). The effects levels for porewater ammonia (37.5% in Broad Creek versus 27.3% in Okatee River) were generally comparable in both systems. This suggests that chemical contaminant effects were generally similar in comparisons of the Broad Creek and the Okatee River. In the Okatee River, there was greater toxicity from ammonia, but only in tidal creek stations. Regression analysis indicated that clam bioassay results were significantly correlated (Rho = 0.52; P < 0.003) with sediment As concentrations but not sediment lindane concentrations. This would suggest that clam toxicity was related to sediment arsenic concentrations. Wirth et al. (1996) reported EC_{50} for oyster spat at 12.5 ppm very similar to the range of arsenic concentrations measured at site with arsenic ERL exceedances, which had toxicity in this study.

Juvenile clam toxicity was generally greatest in tidal creek habitats in both Broad Creek (83.3%) and the Okatee River (100%) when compared to river (Broad Creek = 16.7%; Okatee River = 33.3%) stations. High juvenile clam mortality was also measured in intertidal habitats in both Broad Creek (67%) and the Okatee River (100%). This suggests that toxicity was more prevalent in tidal creek habitats closest to land-based pollution sources which generally had higher levels of ammonia in addition to enriched levels of chemical contaminants or in depositional environments (intertidal sites) in larger portions of each watershed.

Oyster Fertilization and Development Assays:

The results of sediment elutriate toxicity tests assessing effects on oyster fertilization or development generally indicated no evidence of toxicity. Only one site in Broad Creek (7%) and none of the sites in the Okatee River had inhibited oyster fertilization, while no sites in either watershed had altered oyster development (Tables 4.12 - 4.13 and Figures 4.13-4.14). In addition, regression analysis (Table 4.10) indicated only a slight correlation between oyster fertilization and sediment arsenic concentrations (Rho = 0.35; $p < 0.0574$). Spatially, toxicity was only observed at Broad Creek tidal creek site T-2. No effects on oyster fertilization or development were observed at intertidal or river sites in either watershed. However, it must be remembered that these assays were conducted with gametes from healthy oysters collected from a generally pristine reference site in the Charleston Harbor area and as a result "healthy" oyster gametes were used. Different results might be obtained if oysters were "less healthy", which would occur under stressful conditions. In addition, the elutriate bioassay approach may only reflect the contaminants that would be eluded under relatively mild conditions. Factors such as pH, salinity, and dissolved oxygen shifts could result in substantially greater release of pollutants from sediments than would be observed under these conditions. As a result, these assays may not reflect the full potential for toxic effects of the habitats on gamete viability of native organisms.

CONCLUSIONS:

The general consensus expressed by scientists planning this study was that the increased urbanization found at the Broad Creek watershed would generally have adverse effects on the environmental quality of the sediment microhabitat in this watershed. Sediment geochemistry results indicated that sediment grain size was generally coarser in all tidal creeks and several (2/3) intertidal sites in Broad Creek when compared to the Okatee River. These coarser, sandier sediments in Broad Creek are generally more indicative of erosion of terrigenous sediments associated with increased urbanization. River sites within both Broad Creek and the Okatee River were sand dominated sediments due to the larger tidal range and greater hydrological environment in river stations, which were more erosional environments. Thus, the extent of urban influences appears to be at the tidal creek and tidal river interface. Similarly, sediment TOC was generally equivalent in inter-site comparisons among different microhabitats within each system. Generally, higher sediment TOCs were observed in intertidal sites and some of the tidal creek habitats than in subtidal stations. The fact that sediment TOCs in Broad Creek were not increased when compared to the Okatee River suggests that the observed increased water column TOCs in Broad Creek must be enriched in dissolved rather than particulate carbon, as particulate carbon would settle out into sediments and be reflected in higher sediment TOC levels. In Broad Creek this was not the case, rather sediment TOC levels were equivalent in comparisons with the Okatee River. This implies a significant groundwater delivery route for increased water column TOC via DOC in groundwater. Urbanization activities, such as increased land application of sewerage may potentially contribute to this source of DOC. Additional study of this issue is

warranted in Broad Creek, with a particular emphasis on evaluation of land application practices for sewerage disposal.

Another basic premise of this study was that Broad Creek was more chemically contaminated than the Okatee River due to the increased urbanization found in the Broad Creek watershed. Results of chemical contaminant analysis clearly indicated that Broad Creek was not as chemically contaminated as previously anticipated and that the Okatee River was slightly more polluted than was originally thought. Sediment concentrations of dieldrin, acenapthene, arsenic, and lindane were greater than regional and national SQG thresholds (Table 4.14 and Figures 4.15-4.17). Arsenic concentrations were only slightly elevated relative to SQGs and generally reflected the high regional background levels found in estuarine sediments of the southeastern U.S. (Hyland et al., 1998; Long et al., 1998). Lindane concentrations were elevated in sediments in both watersheds, at concentrations > SQG thresholds and midpoints for toxic effects in both watersheds.

Lindane is a chlorinated hydrocarbon insecticide with a fully chlorinated benzene ring. It is used in both agricultural and urban applications as a soil fumigant and foliar treatment on fruit and nut trees as well as vegetable and ornamental plants (Farm Chemical Handbook, 1992). Pait et al. (1992) found that more than 120,590 pounds of active ingredient pesticides (PAI) were used on the estuarine region draining into St. Helena Sound near Beaufort, SC. Similarly, greater than 138,578 PAI pesticide were applied in upland areas adjoining the estuarine drainage areas of the Broad River versus only 92,976 PAI pesticide which were applied in upland areas adjoining the Savannah River. A comparison of the agricultural watershed size relative to pesticide application rates yielded pesticide usage estimates which ranged from 12,300 PAI/square mile for Broad River to 2875 PAI/square mile for St. Helena Sound to 894 PAI pesticide/square mile in the Savannah River. Agricultural lands account for 22-31% of land-use within each of these three SC watersheds. This clearly indicates the pervasive use of pesticides on agriculture within estuarine drainage areas of Beaufort County. As more agricultural lands are converted to urban areas, the amount of toxic pesticides will be reduced, but other contaminants such as PAHs formed by the combustion of petroleum, may be discharged in urban NPS runoff.

Siewicki (1995) estimated *per capita* PAH loading from urban areas of SC at 0.53 g of fluoranthene/*capita*/year, which was very similar to loading rates for Rhode Island of 0.58 g of fluoranthene/*capita*/year (Hoffman et al., 1983) and for California of 0.53 g of fluoranthene/*capita*/year (Eganhouse and Kaplan, 1981; Eganhouse et al., 1981). Hoffman et al. (1983) found that the flux of fluoranthene from parking lots was estimated at 55 g of petroleum hydrocarbon/hectare/cm of rain or 33 mg of fluoranthene/hectare/cm of rain (Siewicki, 1995). In addition, the antecedent dry weather period did not affect petroleum hydrocarbon loadings (Hoffman et al., 1982; 1983). Persistent organochlorine pesticides, such as lindane, may persist in estuarine sediments after agricultural lands are converted to urban areas, adding to the toxicity potential of sediments as increased PAH discharges occur with urbanization. Surprisingly, only one ERL exceedance was found for PAHs in Broad Creek or the Okatee River. In fact, PAH levels in Broad Creek were comparable to levels found in the ACE Basin. An additional comparison of 10 selected

PAHs commonly measured in another urban watershed, in SC, Murrells Inlet, located just south of the Myrtle Beach Grand Strand, and in North Inlet, a NOAA NERRS site are depicted in Figure 4.15. Note the much higher PAH sediment concentrations in Murrells Inlet when compared to North Inlet, Broad Creek and the Okatee River. In fact, PAH sediment concentrations in Broad Creek and Okatee River were slightly lower than measured in pristine North Inlet, possibly due in part to the higher tidal range found in Beaufort County. In contrast to PAHs, comparison of metals concentrations indicates that there was no evidence of metals enrichment between the two systems (Figure 4.15). The much higher PAH levels found in Murrells Inlet clearly demonstrate the impact of over-development of coastal areas of SC. The much lower PAH levels in Broad Creek sediments and comparability with sediment concentrations in North Inlet and Okatee River, implies that zoning regulations employed in Beaufort County have been effective in reducing PAH loadings in Broad Creek. While high sediment PAH concentrations have been measured in fuel docks and boat-berthing areas of Broad Creek, there was no evidence of PAHs being transported far from marina sites (Marcus et al., 1988). This study supports these conclusions by Marcus et al. (1988) and suggests that marina operators should continue their vigilance in reducing PAH loadings within Broad Creek. The use of setbacks, buffer strips and stormwater retention/detention ponds appear to have been effective in reducing PAH loadings within Broad Creek. Yet, toxicity was measured in Broad Creek sediments, due primarily to ammonia, arsenic, lindane and the cumulative effects of multiple contaminants and/or stressors (Table 4.14).

An evaluation of the overall status of sediment quality (combining sediment chemistry, ERL/ERM and TEL/PEL sediment quality guidelines, and laboratory bioassays) (Table 4.14) indicated that 5 sites in Broad Creek (33%) and 2 sites in Okatee River (13%) were degraded (Figures 4.16 -4.17). Sites in Broad Creek with degraded sediment quality were the result of ERM exceedance (1/5 sites), toxicity in multiple bioassays (3/5 sites) or both (1/5 sites). The sites in the Okatee River with degraded sediment quality were the result of both ERM exceedances (1/5 sites) and toxicity in multiple bioassays (1/5 sites). Additional analysis indicated that 4 sites in Broad Creek (27%) and 9 sites (60%) in the Okatee River had sediments, which were marginally degraded. Sites in Broad Creek and Okatee River with marginally degraded sediment quality were the result of ERL/TEL exceedances or high ERM/PEL Quotients and toxicity in a single bioassay. A total of 6 sites (40% of the sites) in Broad Creek and 4 sites (27%) in the Okatee River had good overall sediment quality.

What this overall evaluation of sediment quality indicates is that in Broad Creek, as it has become more developed, many sites have moved from marginally degraded into the degraded classification of sediment quality. Most of this change in classification was the result of toxicity being observed in multiple bioassays, rather than discriminate increase in any one class of chemical contaminants. The bioassays used in this study were designed to provide evidence of alterations and changes in clam growth, bacterial respiration rate and oyster fertilization/development rates. All of these end-points are sublethal (an effect < death) in nature and provide *"early warning"* indications of faunal stress. Within Broad Creek, there are clear indications of *"early warning"* potential to cause faunal stress based upon these bioassays. This finding is supported by our

assessment of the condition of benthic communities in Broad Creek (see Chapter 5) which represent a biological constituent of the estuarine ecosystem that are both closely affiliated with the sediments and sensitive to long-term chronic exposure effects.

In the Okatee River, we see evidence of multiple species faunal stress at only two degraded sites. More sites in Okatee River were marginally degraded rather than degraded, suggesting that sediments do not contain high levels of chemical contaminants which are stressful to marine fauna. Generally, sediment contaminant levels were somewhat higher in Okatee River than was originally anticipated. In particular, sediment concentrations of the persistent pesticide lindane were pervasive in river sediments. For example, in Okatee River where most lindane usage was agricultural, lindane was found in high concentrations in both river sediments and tidal creek sediments. Tidal creek sediments would be closer to the upland agricultural sources, yet lindane was found to be transported away from the original source into river sediments. This spatial distribution pattern was likely due to the long half-life of lindane of 6-22 days in humic peat to 3-22 days in sandy soils (Verschueren, 1996). Persistence will be much greater in anoxic estuarine sediments. Thus, it is important that nonpersistent pesticides be used where possible in existing agricultural areas of the Okatee River. This will prevent additional input of persistent chemical contaminants from agriculture within this watershed. In urban areas, such as residential housing and golf courses, contemporary pesticide usage should also be targeted for nonpersistent pesticides, where possible. The use of nonpersistent pesticides will become more important as the Okatee River watershed is urbanized. Currently, Okatee River is not highly developed and as rapid urban development of this watershed occurs, it will be important to provide adequate zoning regulations to protect this watershed from the discharge of chemical contaminants via urban NPS runoff into the system. In urbanized Broad Creek, it was noted that there is much more widespread degradation of sediment quality and this was undoubtedly the result of increased urbanization around and within the watershed. If urban contaminant discharges of PAHs, trace metals and pesticides via NPS runoff are not adequately controlled in the Okatee River there will the additional introduction of chemical contaminants into sediments within the Okatee River watershed. This urban insult, in combination with the current levels of lindane and arsenic, may adversely affect early warning stress indicators used in this study and may ultimately affect epibenthic and benthic fauna.

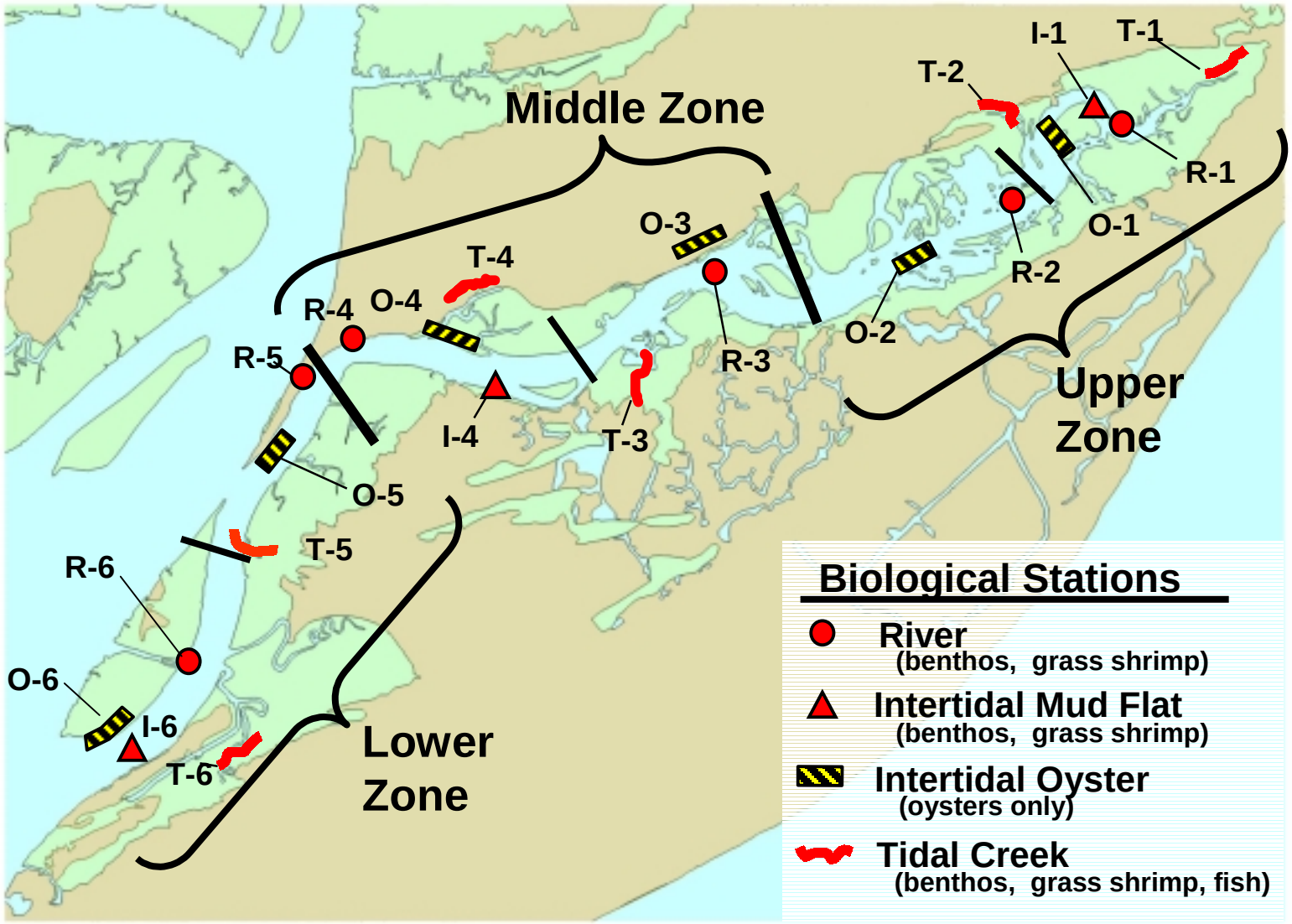


Figure 4.1 Broad Creek sampling sites for chemical contaminants in sediment. Samples were collected from sites where benthos, grass shrimp, and fish were collected.

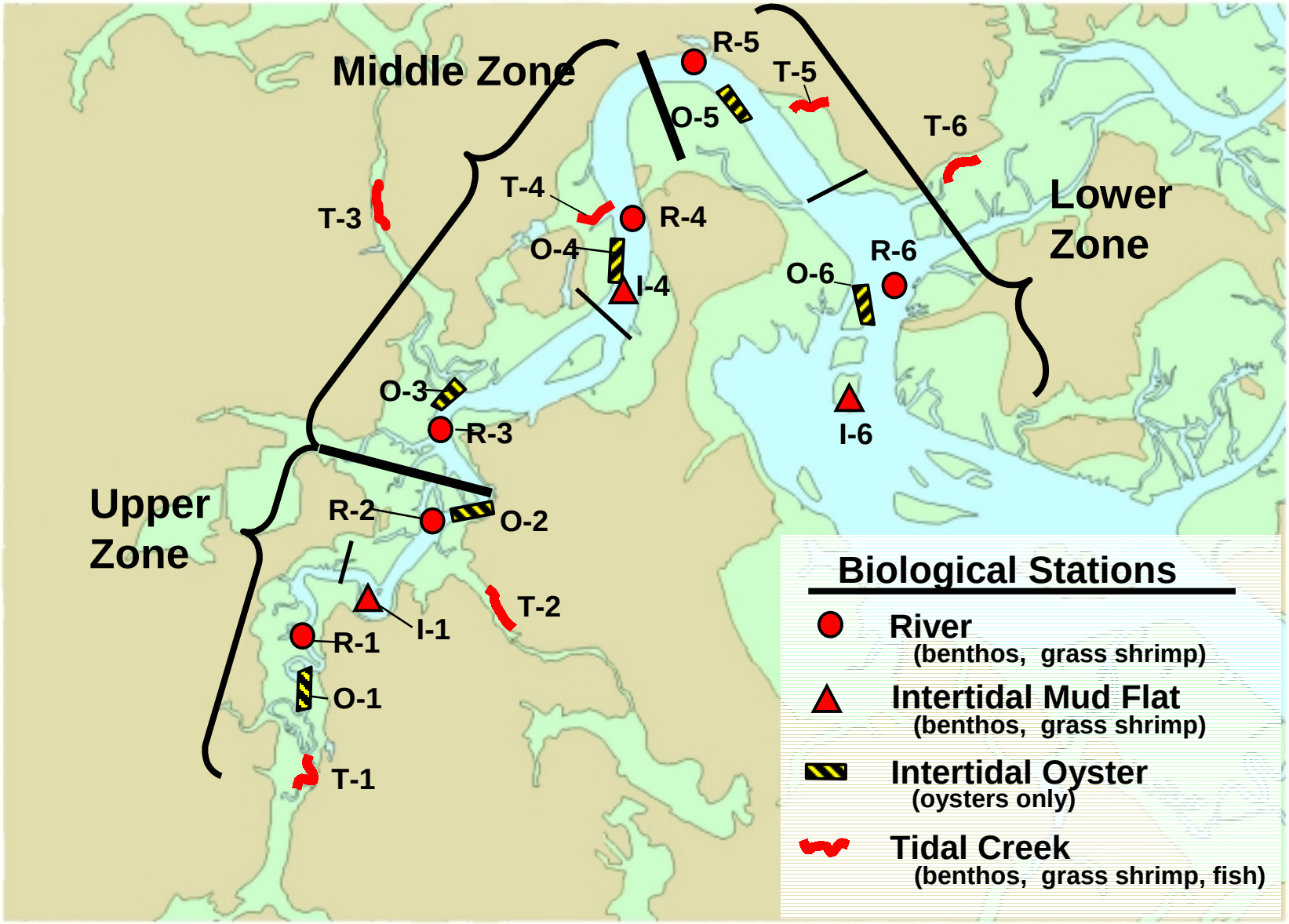


Figure 4.2 Okatee River sampling sites for chemical contaminants in sediment. Sediment samples were collected from sites where benthos, grass shrimp, and fish were collected.

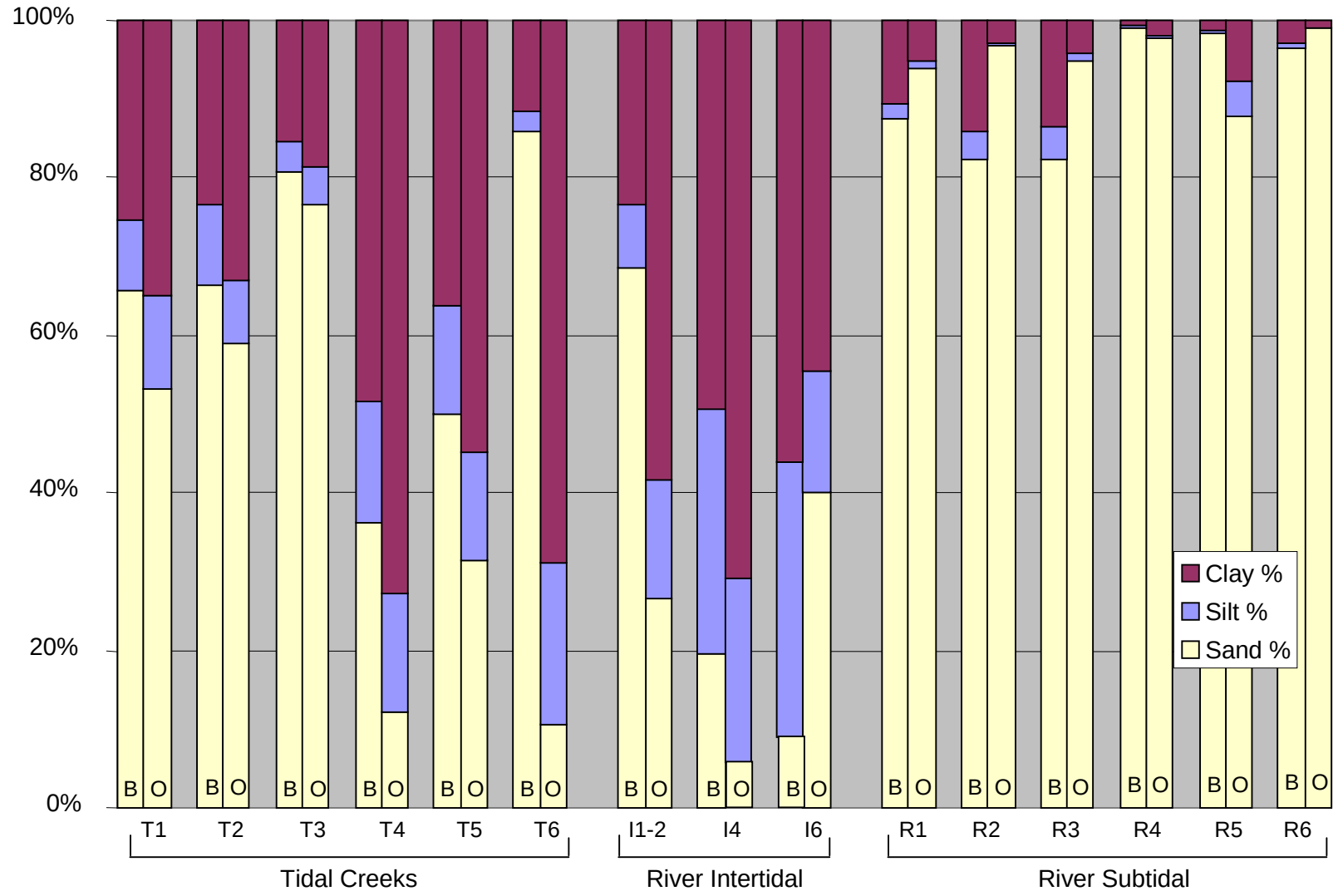


Figure 4.3 Sediment grain size information from composite samples. Note the high sand content in most samples.

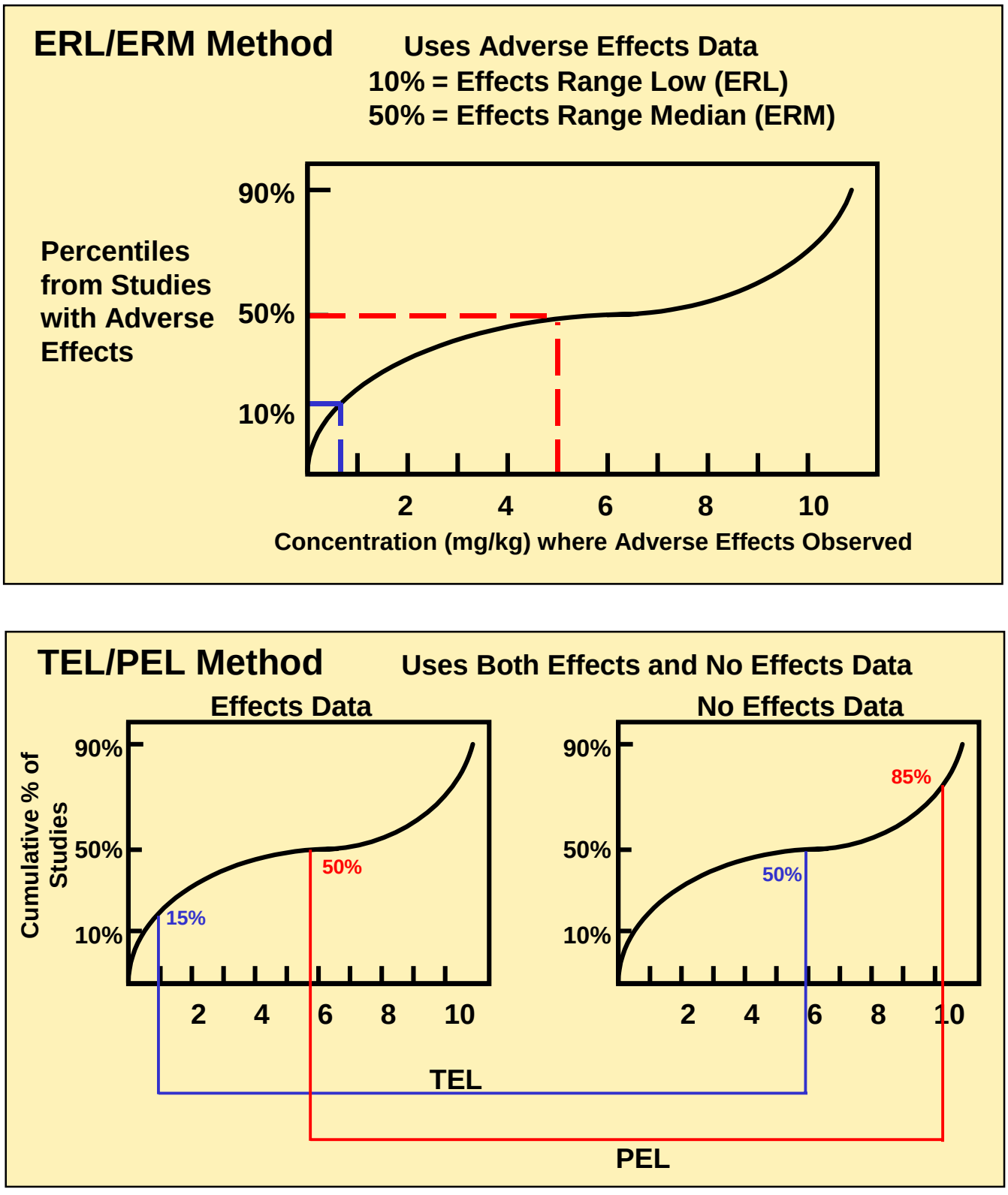
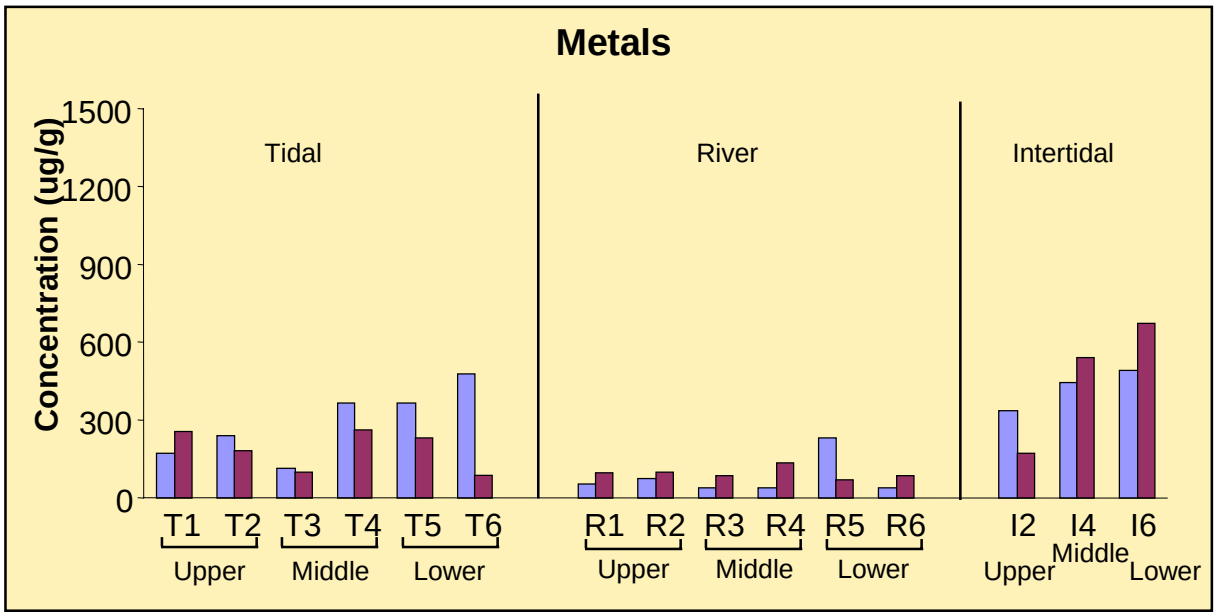


Figure 4.4 Methods for the calculation of Sediment Quality Guidelines (SQGs). The top graph shows the Apparent Effects Threshold methodology for the calculation of ERL and ERM values (Long et al., 1995; 1998). The bottom graph shows the methodology used for the calculation of TEL and PEL values (MacDonald, 1994), which incorporate both adverse and no adverse effects data.



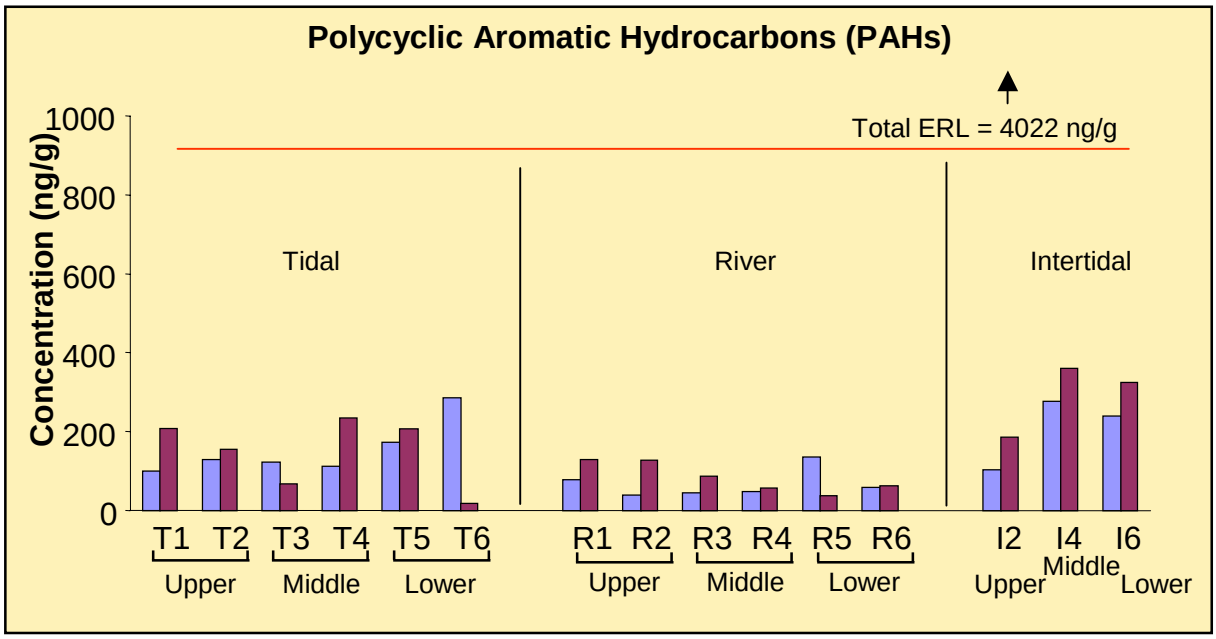


Figure 4.5 Total metals and total PAH concentrations measured at Okatee River (blue bars) and Broad Creek (red bars) sites. Note the comparable levels of metals and PAHs between systems and the low concentration of PAHs overall.

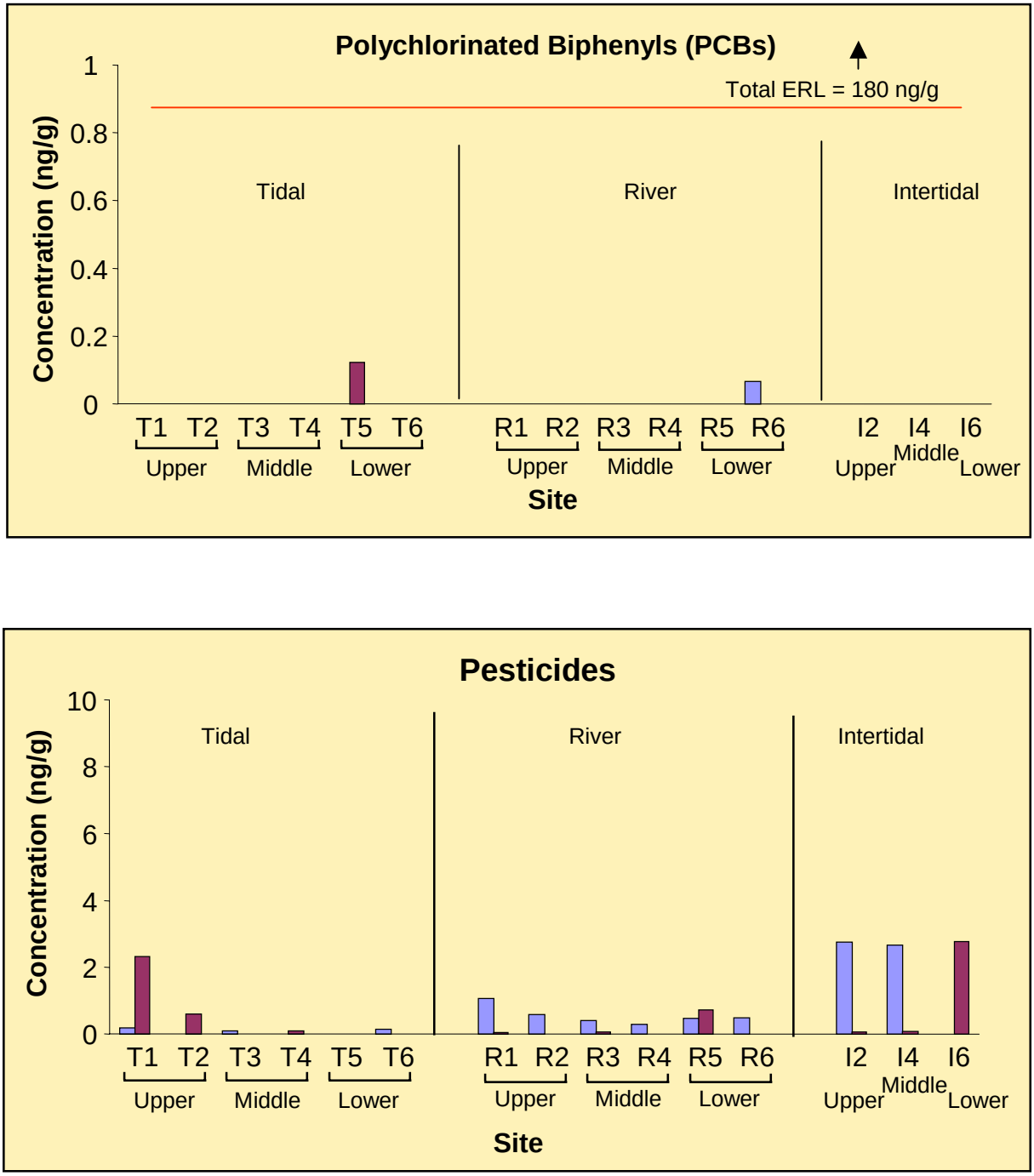


Figure 4.6 Total PCB and total pesticide concentrations measured at Okatee River (blue bars) and Broad Creek (red bars) sites. Note the general absence of PCBs in both systems but the pervasive occurrence of pesticides in both systems.

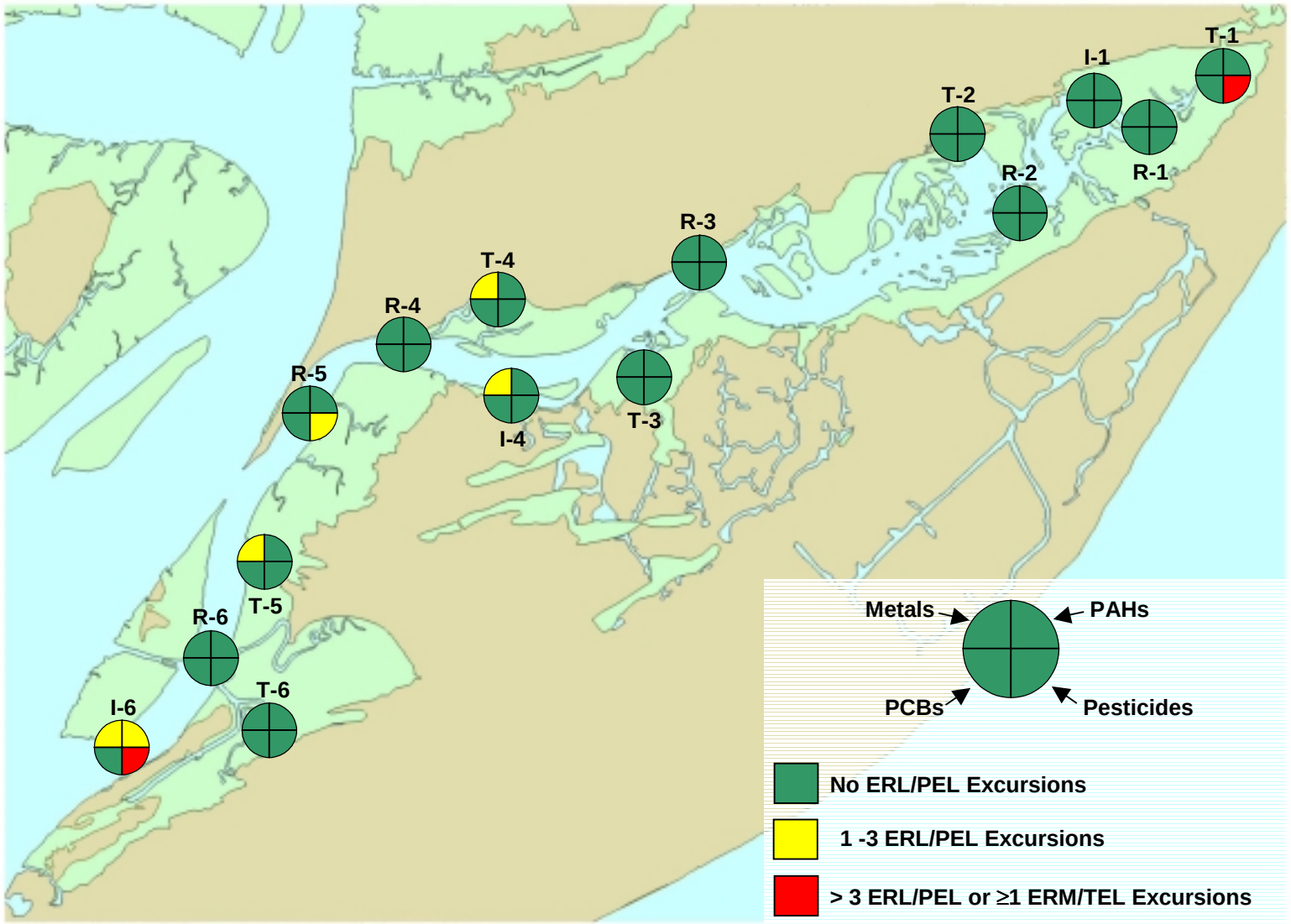


Figure 4.7 Map of Broad Creek showing excursions for Sediment Quality Guidelines (SQGs). Only 40% of the sites had any SQG excursion and only one site had a moderate risk (ERM) excursion.

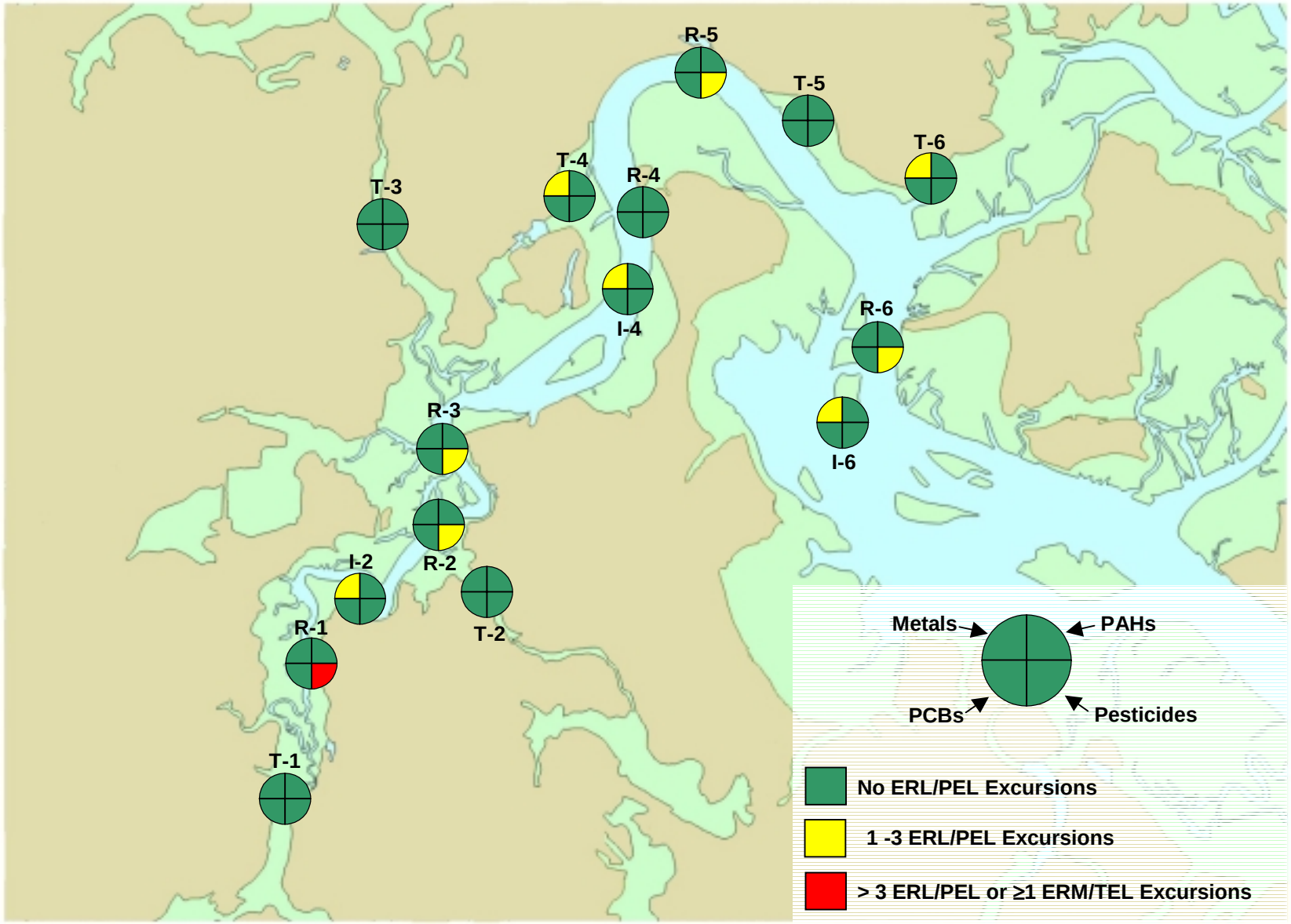


Figure 4.8 Map of Okatee River showing excursions for Sediment Quality Guidelines (SQGs). ERL excursions occurred at 67% of the sites, but no ERM excursions were found.

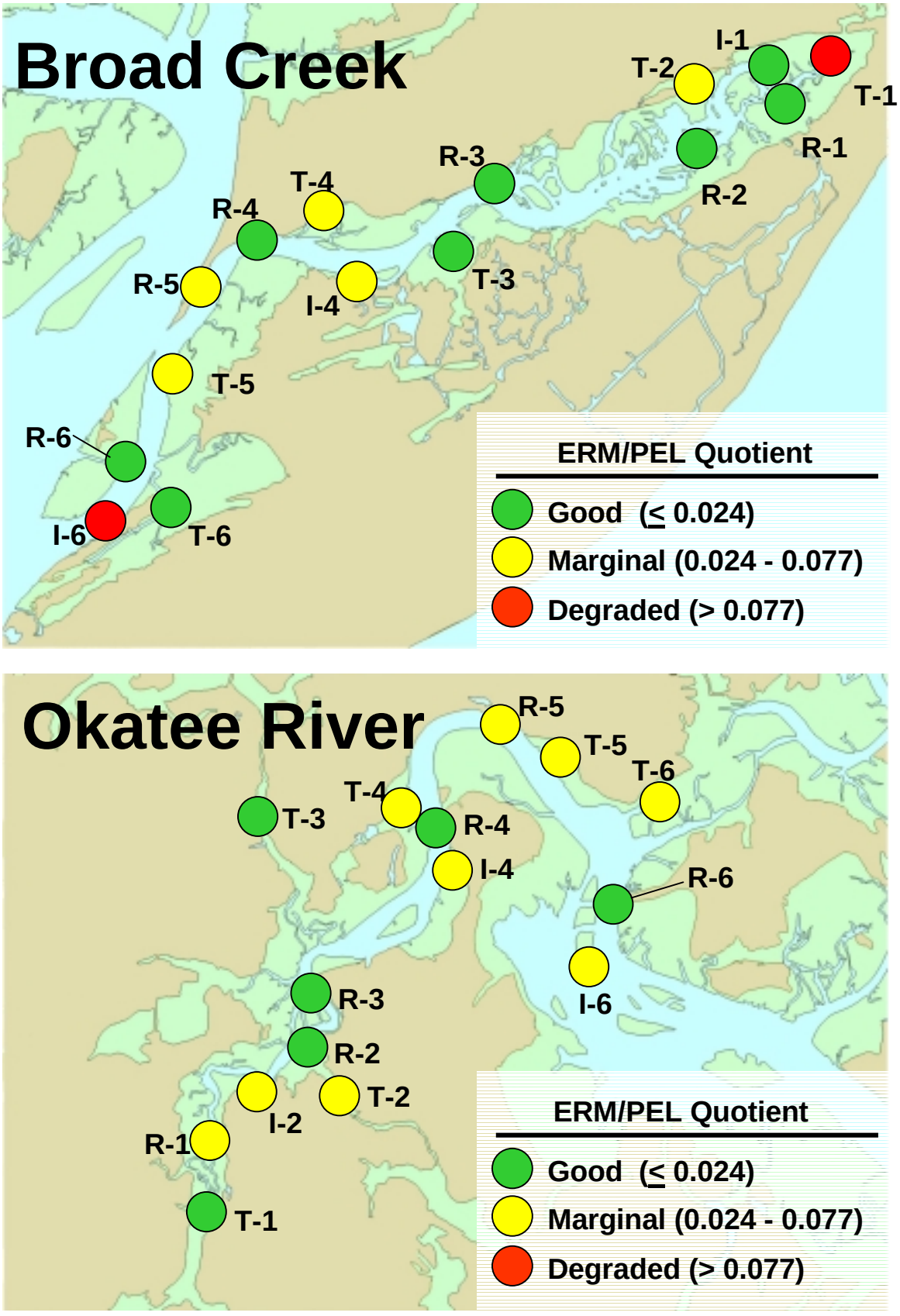


Figure 4.9 Maps showing potential risk of contamination due to overall cumulative sediment contaminant levels.

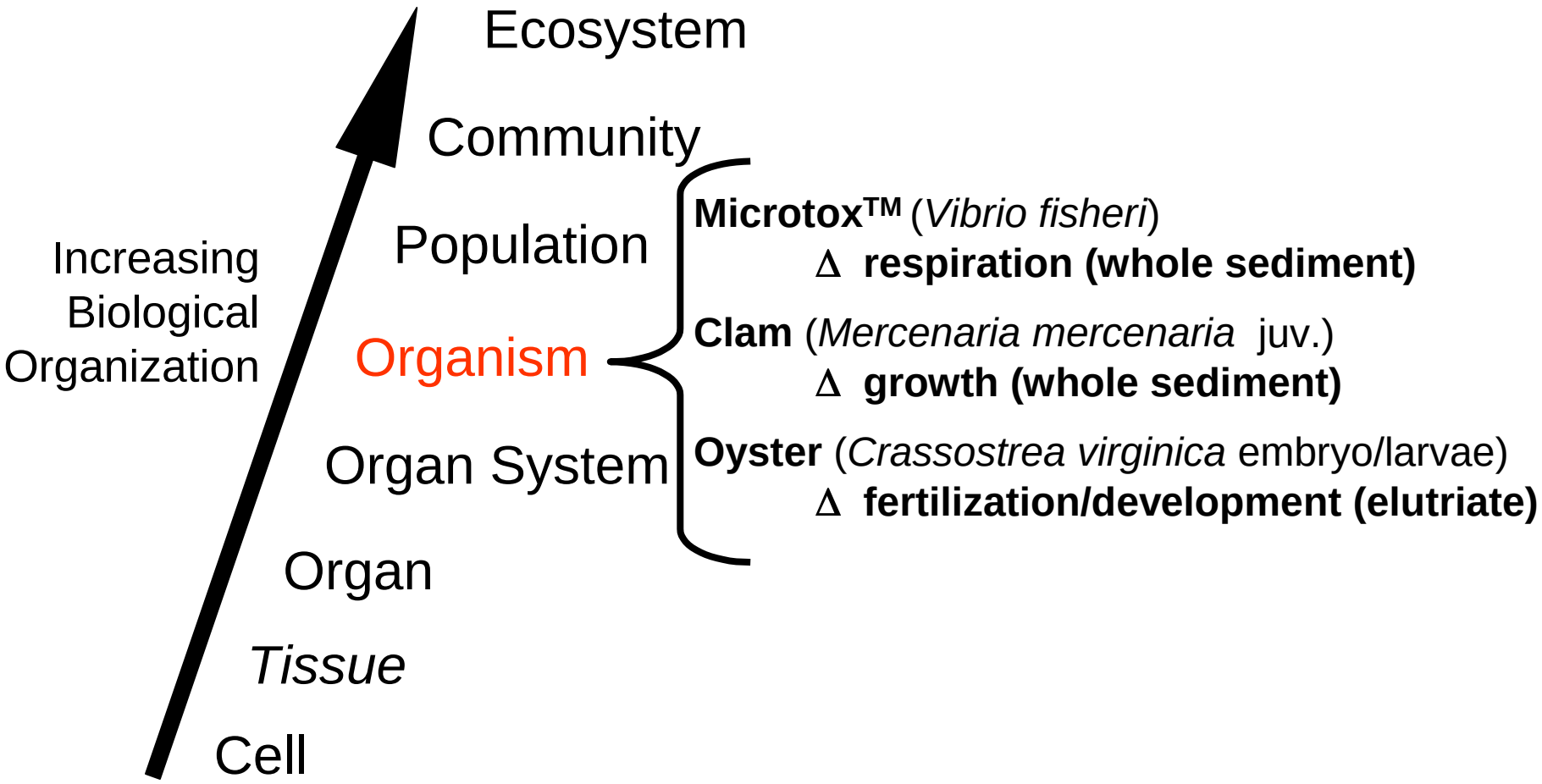


Figure 4.10 Diagram showing the levels of biological organization that may be addressed in toxicity testing. All assays conducted for this study focused on the organismal level, which represents a traditional level between suborganism and population responses.

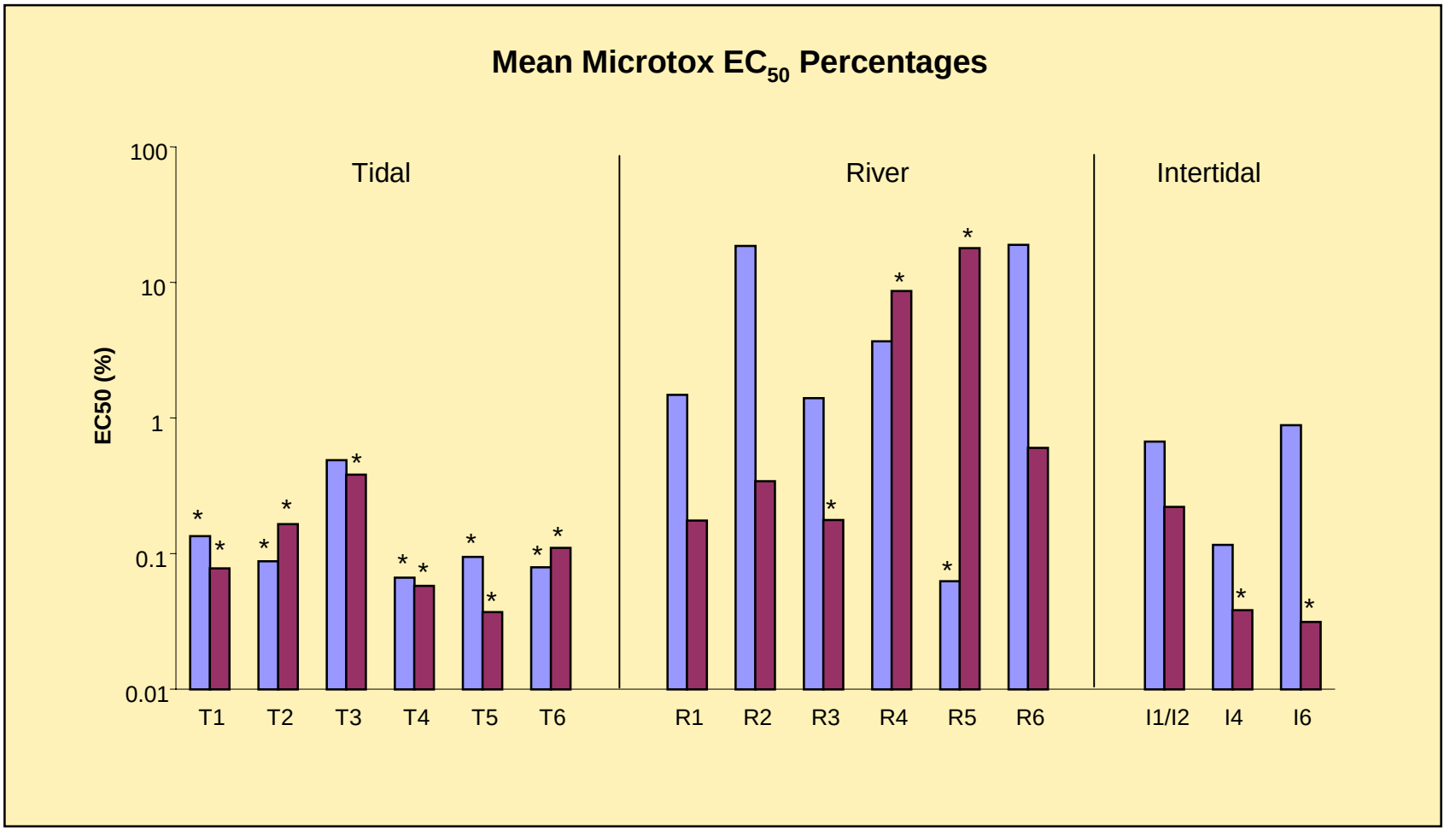


Figure 4.11 Microtox EC_{50} measurements for sediments from the Okatee River sites (blue bars) and Broad Creek (red bars). Asterisks indicate potential toxicity based on comparison to regional EMAP values.

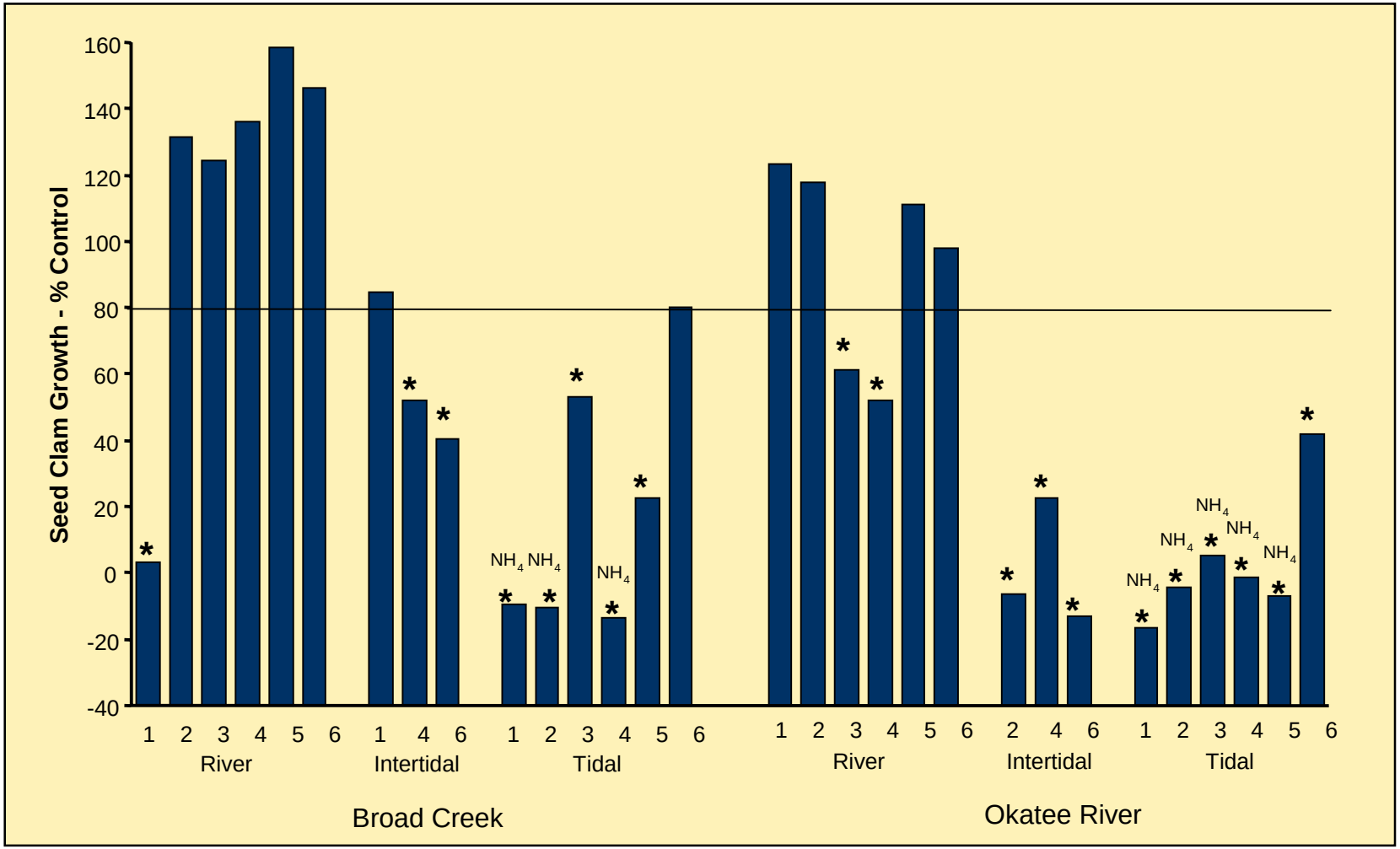


Figure 4.12 Site specific results of seed clam growth assays. Sites were classified as toxic (indicated with an *) when growth was less than 80% of controls and significantly different ($p<0.05$). The sites that had elevated porewater ammonia concentrations are also indicated.

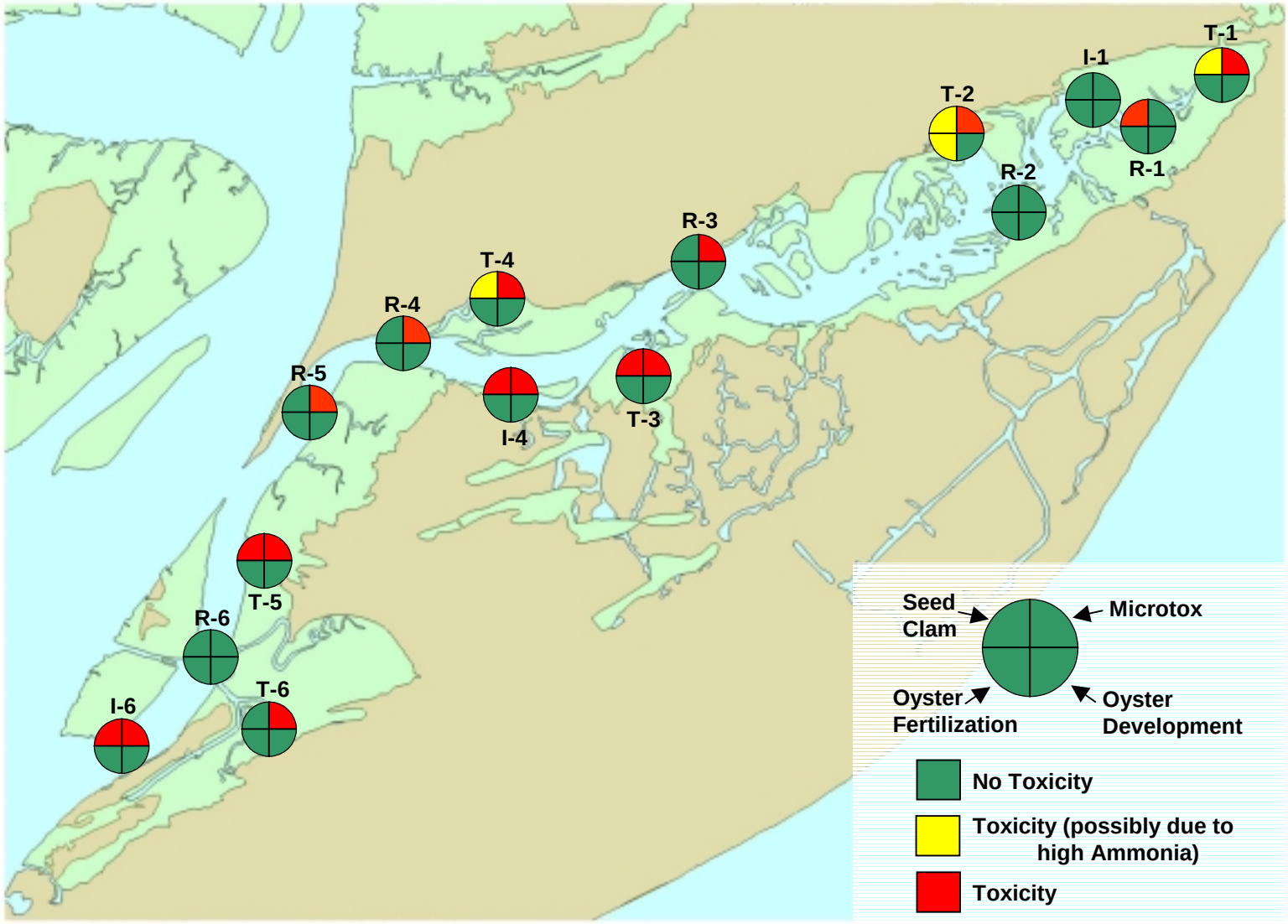


Figure 4.13 Broad Creek toxicity test results.

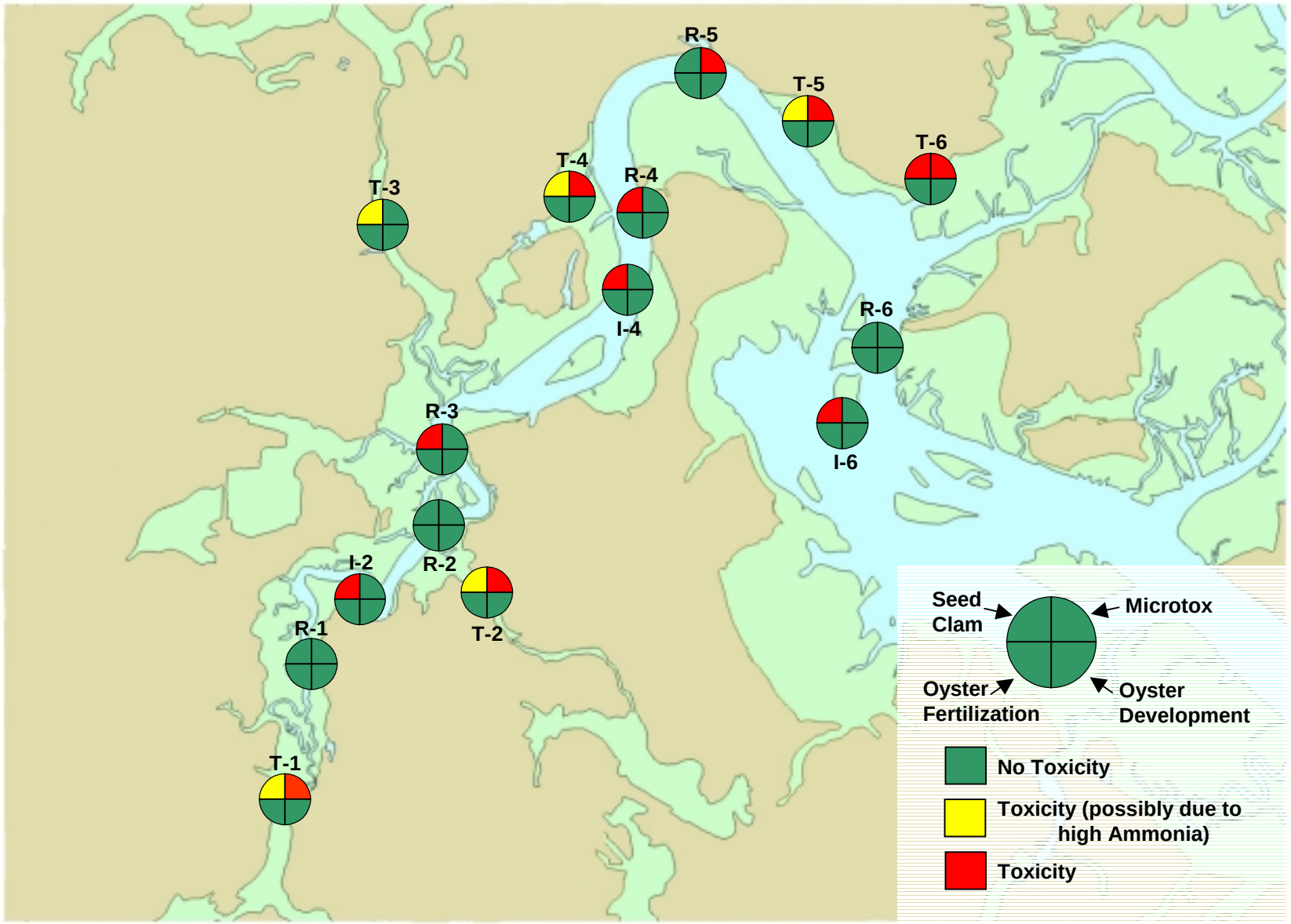


Figure 4.14 Okatee River toxicity test results.

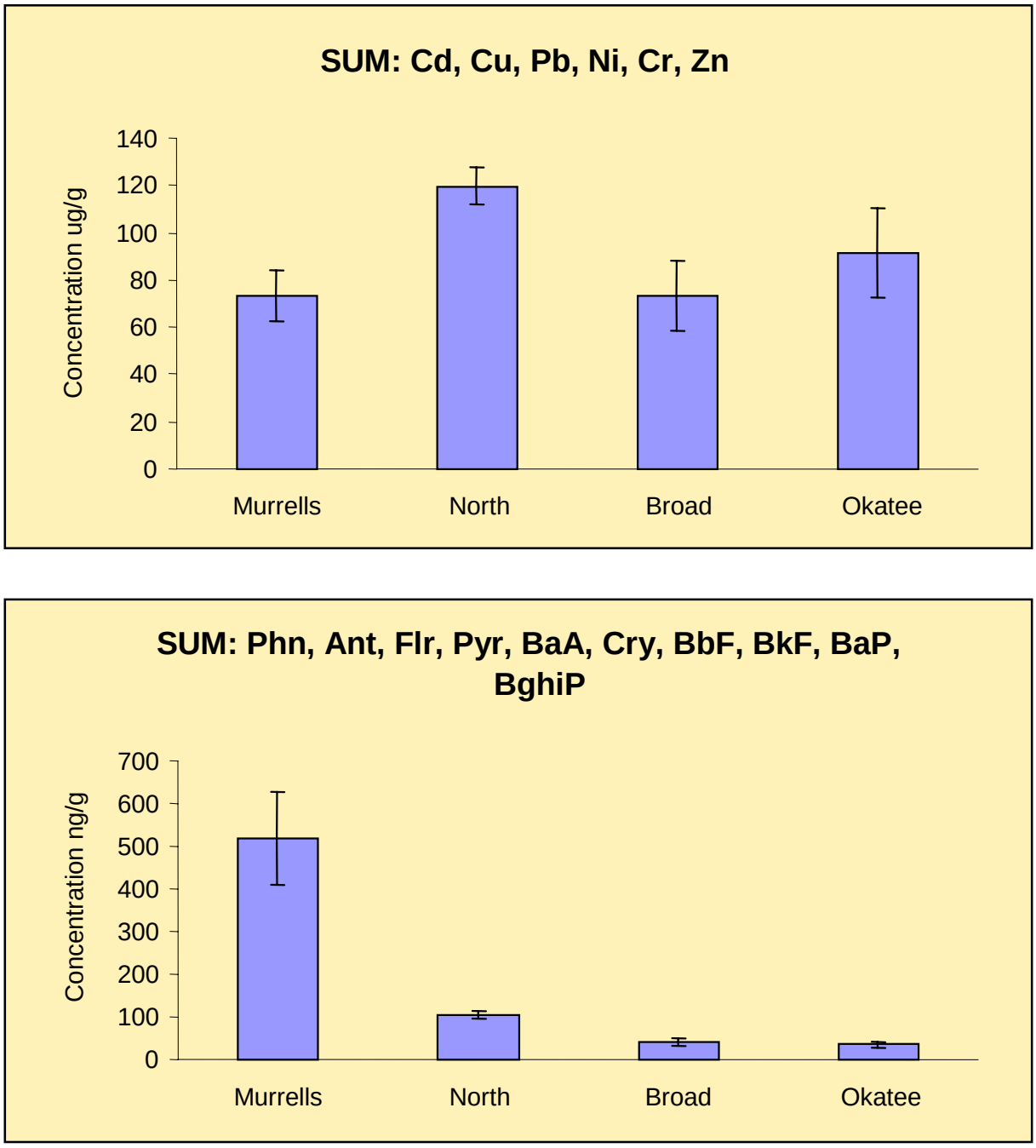


Figure 4.15 Comparison of Metal (top graph) and PAH Levels (lower graph) in Murrells Inlet, North Inlet, Broad Creek and Okatee River, South Carolina (Mean ± SEM).

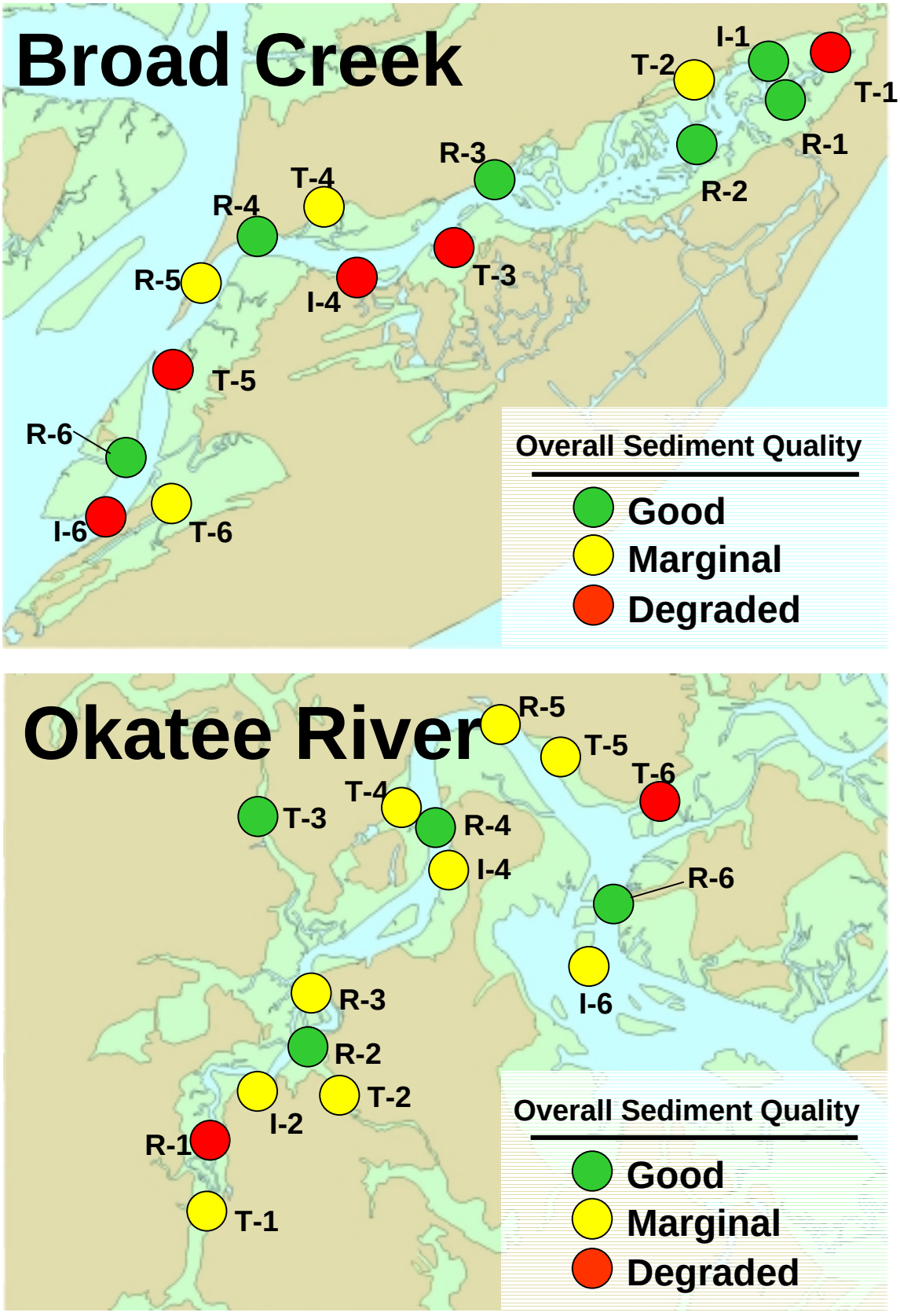
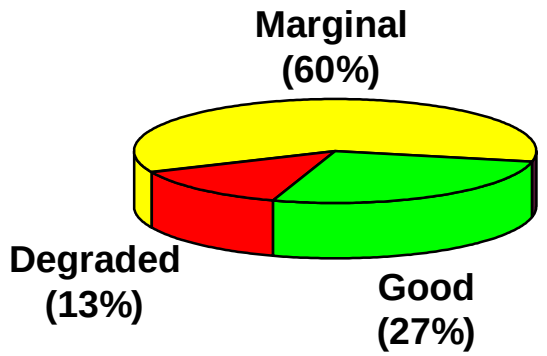


Figure 4.16 Map of Broad Creek and Okatee River showing classifications of overall sediment quality.

Cumulative Effects

Okatee River:

- 2 of 15 (13%) sites degraded
- 9 of 15 (60%) sites marginally degraded



Broad Creek:

- 5 of 15 (33%) sites degraded
- 4 of 15 (27%) sites marginally degraded

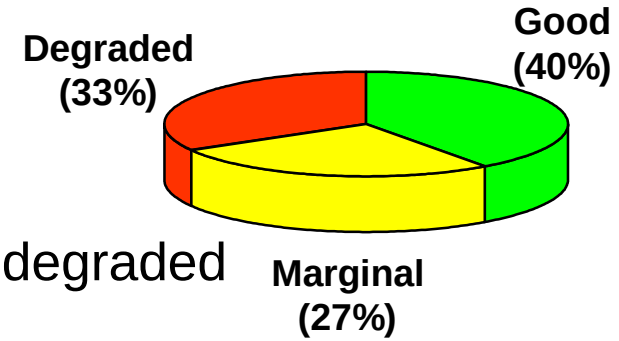


Figure 4.17 Overall ratings of the environmental health of Broad Creek and Okatee River based on those parameters measured for the time period studied.

Table 4.1 Summary of the sediment quality parameters examined for the Broad Creek/Okatee River study

Sediment Quality Parameter	Metric/Test	Analyses/Measurement
Physical Sediment Characteristics	Grain Size	% fine grain sediments (mud, silt, & clays)
		% coarse sediments (sand)
		total organic carbon (TOC)
Contaminant Chemistry	Trace Metals	Al, As, Cd, Cr, Cu, Pb, Mn, Hg, Ni, Ag, & Zn
	Polycyclic Hydrocarbons	24 analytes
	Polychlorinated Biphenyls	27 congeners
	Pesticides	16 pesticides/analytes
Sediment Toxicity Tests & Bioassays	Microtox (*Vibrio fisheri*)	respiration
	Seed Clam Growth	growth
	Oyster	fertilization and development

Table 4.2 Summary of sediment composition at all sites examined in the Broad Creek and Okatee River. The % sand, silt, and clay are shown, as well as the % total organic carbon (TOC).

Creek	Zone	Station	Sand %	Silt/Clay %	Silt %	Clay %	TOC %
Okatee River	tidal creek	1	53.3	46.7	11.7	35.0	1.53
		2	58.9	41.1	8.2	33.0	1.85
		3	76.5	23.5	5.0	18.5	1.57
		4	12.3	87.7	14.9	72.8	3.10
		5	31.5	68.5	13.7	54.8	2.37
		6	10.7	89.3	20.4	68.9	2.97
	river subtidal	1	93.8	6.2	1.0	5.2	0.14
		2	96.8	3.2	0.4	2.8	0.11
		3	94.9	5.1	0.8	4.2	0.07
		4	97.8	2.2	0.2	2.0	0.11
		5	87.8	12.2	4.4	7.8	0.77
		6	98.9	1.1	0.2	0.9	0.07
	river intertidal	2	26.7	73.3	15.0	58.3	2.00
		4	5.8	94.2	23.4	70.8	2.20
		6	40.0	60.0	15.4	44.5	1.59
Broad Creek	tidal creek	1	65.8	34.2	8.9	25.3	1.79
		2	66.4	33.6	10.0	23.5	1.59
		3	80.6	19.4	4.0	15.4	0.98
		4	36.2	63.8	15.5	48.3	2.50
		5	49.9	50.1	13.8	36.3	2.52
		6	85.9	14.1	2.6	11.5	0.53
	river subtidal	1	87.6	12.4	1.8	10.5	0.36
		2	82.3	17.7	3.5	14.2	0.64
		3	82.4	17.6	4.1	13.6	0.53
		4	99.2	0.8	0.1	0.7	0.05
		5	98.3	1.7	0.3	1.4	0.12
		6	96.4	3.6	0.9	2.7	0.16
	river intertidal	1	68.6	31.4	7.9	23.5	0.91
		4	19.6	80.4	30.9	49.5	2.72
		6	9.1	90.9	34.9	56.0	2.85

Table 4.3 Summary of metal contaminants in sediments collected from Okatee River and Broad Creek. Values are ug/g except for Al (expressed as %). The ΣPC for ERLs and ERMs are shown when As is included or excluded; the % change includes the change in ΣPC values when As is excluded. ERL and ERM values are shown; ERL exceedences are shaded.

STATION		% Al	As	Cd	Cr	Cu	Pb	Hg	Ni	Ag	Zn	Mn	åPC-ERM	åPC-ERM (-As)	% Change
Okatee River															
Tidal Creek	1	3.10	6.76	0.042	31.7	4.04	11.4	0.053	7.88	<0.02	28.7	80.5	0.55	0.45	17.53
	2	3.20	5.71	0.048	34.8	4.82	12.9	0.057	7.90	<0.02	32.1	146	0.57	0.49	14.34
	3	2.04	4.04	0.036	22.3	2.85	8.66	0.035	4.85	<0.02	20.6	50.1	0.36	0.31	15.82
	4	7.02	**14.0**	0.107	71.2	11.4	22.8	0.104	19.0	<0.02	67.8	159	1.23	1.03	16.25
	5	3.89	8.06	0.058	42.1	6.78	14.4	0.061	10.3	<0.02	38.5	244	0.70	0.59	16.34
	6	6.86	**11.4**	0.106	71.6	11.3	22.8	0.078	18.7	<0.02	66.7	273	1.15	0.99	14.18
Subtidal	1	0.50	0.04	0.04	6.68	0.71	2.29	0.026	1.92	<0.02	6.48	36.4	0.13	0.13	0.41
	2	0.15	1.13	0.036	2.02	0.29	0.16	0.017	1.83	<0.02	3.17	67.6	0.09	0.08	17.06
	3	0.25	0.04	0.036	3.98	0.50	0.38	0.012	1.89	<0.02	4.47	28.3	0.08	0.08	0.62
	4	0.22	0.04	0.03	3.21	0.29	0.38	0.016	1.85	<0.02	3.60	32.6	0.08	0.08	0.61
	5	2.95	3.37	0.386	35.5	4.94	9.98	0.043	8.87	<0.02	34.0	132	0.56	0.52	8.54
	6	0.08	0.07	0.033	1.59	0.28	0.15	0.022	1.77	<0.02	3.46	32.8	0.08	0.08	1.11
Intertidal	2	5.87	**10.4**	0.165	63.7	9.44	19.2	0.074	15.7	<0.02	58.5	159	1.01	0.86	14.68
	4	6.69	**13.0**	0.113	75.7	10.30	19.8	0.068	19.4	<0.02	66.5	240	1.17	0.98	15.94
	6	5.31	**14.30**	0.105	55.2	8.42	18.8	0.063	14.6	<0.02	51.4	328	0.98	0.77	20.87
Broad Creek															
Tidal Creek	1	3.07	6.20	0.064	34.4	11.70	12.7	0.057	7.51	<0.02	32.6	152	0.60	0.51	14.87
	2	2.85	4.92	0.034	29.7	8.81	11.0	0.044	6.87	<0.02	36.9	83.2	0.52	0.45	13.47
	3	1.38	4.58	0.031	15.8	4.67	4.97	0.020	3.79	<0.02	20.0	44.4	0.30	0.24	21.66
	4	3.78	**9.44**	0.073	41.1	9.91	14.6	0.055	10.6	<0.02	46.6	140	0.75	0.62	17.90
	5	3.06	**12.1**	0.031	34.6	6.78	11.3	0.045	8.74	<0.02	35.5	120	0.67	0.49	25.97
	6	1.10	4.60	0.029	12.4	3.25	5.16	0.025	3.34	<0.02	13.8	45	0.27	0.21	24.24
Subtidal	1	1.18	0.726	0.051	14.8	3.88	4.17	0.033	3.68	<0.02	16.0	53.8	0.25	0.24	4.21
	2	0.98	2.81	0.071	13.1	3.19	3.27	0.024	2.88	<0.02	15.7	58.5	0.24	0.20	16.92
	3	0.74	2.01	0.069	9.11	2.52	2.56	0.023	2.31	<0.02	12.7	53.5	0.19	0.16	15.12
	4	0.18	2.62	0.049	2.82	0.51	1.40	0.025	1.37	<0.02	6.72	122	0.14	0.10	27.28
	5	0.16	1.60	0.065	3.31	0.30	0.52	0.014	1.91	<0.02	6.83	57.1	0.12	0.09	19.72
	6	0.48	1.74	0.036	5.96	1.44	2.13	0.018	1.95	<0.02	9.05	72.6	0.14	0.12	17.21
Intertidal	1	2.28	4.79	0.067	26.1	7.66	8.24	0.036	6.83	<0.02	30.9	86.8	0.47	0.40	14.56
	4	6.06	**13.7**	0.073	65.6	17.10	18.9	0.086	17.2	<0.02	70.6	337	1.16	0.96	16.91
	6	6.28	**8.46**	0.078	64.7	13.50	19.9	0.084	18.0	<0.02	66.9	548	1.08	0.95	11.24
ERL			**8.2**	**1.2**	**81**	**34**	**46.7**	**0.15**	**20.9**	**1**	**150**				
ERM			**70**	**9.6**	**370**	**270**	**218**	**0.71**	**51.6**	**3.7**	**410**				

Table 4.4 Summary of concentrations (ng/g) of polycyclic aromatic hydrocarbons (PAHs) found at sites in the Broad Creek and Okatee River sites. Abbreviations for PAHs are described at the bottom. Total PAH concentration, the cumulative ERL, and the cumulative ERM for each site are shown. ERL and ERM values are shown.The one ERL excursion is shaded.

STATION		NAP	2-MN	1-MN	BPN	2,6 DMN	ACY	ACE	2,3,5 TMN	FLO	PHN	ANT	1-MPN	FLU	PYR	BAA	CHR	BBF	BKF	BEP	BAP	PER	IDP	DAHA	BGHIP	Summed Concentration
Okatee River																										
Tidal Creek	1	28.90	23.40	12.20	14.70	<1.71	<0.994	<3.33	<0.915	2.21	6.27	<1.67	<2.12	<2.53	6.29	<3.71	<1.13	5.69	<2.68	<2.57	<4.98	<3.10	<5.00	<1.11	<3.37	99.7
	2	43.80	30.10	17.50	13.60	<1.71	<0.994	<3.33	<0.915	<1.18	5.82	<1.67	<2.12	5.97	4.45	<3.71	<1.13	4.18	<2.68	<2.57	<4.98	4.34	<5.00	<1.11	<3.37	129.8
	3	40.60	29.80	14.60	13.90	<1.71	<0.994	<3.33	<0.915	<1.18	5.38	<1.67	<2.12	<2.53	5.71	<3.71	<1.13	4.57	<2.68	<2.57	<4.98	8.27	<5.00	<1.11	<3.37	122.8
	4	<5.40	8.61	<1.93	17.70	<1.71	<0.994	<3.33	<0.915	<1.18	11.50	3.37	<2.12	13.30	9.62	6.00	<1.13	14.00	5.14	<2.57	7.13	5.49	5.06	<1.11	4.77	111.7
	5	46.50	34.20	19.00	13.00	<1.71	<0.994	<3.33	<0.915	<1.18	9.35	<1.67	<2.12	16.30	11.20	3.80	<1.13	9.97	4.20	5.65	<4.98	<3.10	<5.00	<1.11	<3.37	173.2
	6	96.40	66.90	44.10	26.70	<1.71	<0.994	<3.33	<0.915	<1.18	9.18	2.10	<2.12	9.65	10.30	4.22	<1.13	7.56	<2.68	<2.57	<4.98	5.63	<5.00	<1.11	3.79	286.5
Subtidal	1	23.10	19.50	10.90	4.68	4.72	3.75	3.83	2.18	<1.18	4.32	<1.67	<2.12	<2.53	<2.01	<3.71	<1.13	<2.67	<2.68	<2.57	<4.98	<3.10	<5.00	<1.11	<3.37	77.0
	2	14.10	12.20	6.60	<2.82	1.80	<0.994	<3.33	1.87	<1.18	2.67	<1.67	<2.12	<2.53	<2.01	<3.71	<1.13	<2.67	<2.68	<2.57	<4.98	<3.10	<5.00	<1.11	<3.37	39.2
	3	15.90	12.40	7.26	3.42	1.85	<0.994	<3.33	<0.915	1.26	2.52	<1.67	<2.12	<2.53	<2.01	<3.71	<1.13	<2.67	<2.68	<2.57	<4.98	<3.10	<5.00	<1.11	<3.37	44.6
	4	16.20	13.50	8.54	4.04	<1.71	<0.994	3.81	<0.915	<1.18	3.09	<1.67	<2.12	<2.53	<2.01	<3.71	<1.13	<2.67	<2.68	<2.57	<4.98	<3.10	<5.00	<1.11	<3.37	49.2
	5	33.80	28.30	18.30	7.58	14.20	1.10	5.81	<0.915	<1.18	6.32	<1.67	<2.12	5.37	4.09	<3.71	<1.13	6.22	4.84	<2.57	<4.98	<3.10	<5.00	<1.11	<3.37	135.9
	6	19.00	16.30	9.97	4.60	1.81	<0.994	4.29	<0.915	<1.18	2.70	<1.67	<2.12	<2.53	<2.01	<3.71	<1.13	<2.67	<2.68	<2.57	<4.98	<3.10	<5.00	<1.11	<3.37	58.7
Intertidal	2	25.00	16.70	9.69	7.02	8.66	2.80	<3.33	2.37	2.88	6.32	<1.67	<2.12	<2.53	6.38	<3.71	<1.13	5.91	5.72	<2.57	<4.98	3.81	<5.00	<1.11	<3.37	103.3
	4	65.60	56.40	32.70	13.30	21.10	<0.994	16.00	4.90	<1.18	16.50	<1.67	<2.12	10.40	8.01	4.37	<1.13	10.20	4.05	4.85	<4.98	7.62	<5.00	<1.11	<3.37	276.0
	6	66.80	49.40	28.00	<2.82	<1.71	<0.994	<3.33	<0.915	<1.18	10.30	<1.67	<2.12	<2.53	10.60	7.68	16.20	18.20	7.07	6.27	5.56	4.48	8.54	<1.11	<3.37	239.1
Broad Creek																										
Tidal Creek	1	26.50	19.10	12.90	8.74	1.75	<0.994	<3.33	<0.915	<1.18	11.40	<1.67	<2.12	16.60	13.80	4.75	<1.13	14.00	4.86	10.80	10.50	32.60	8.80	<1.11	11.70	208.8
	2	38.20	28.50	12.70	34.20	<1.71	<0.994	<3.33	1.55	1.72	5.93	<1.67	<2.12	9.21	6.77	<3.71	<1.13	7.42	<2.68	<2.57	<4.98	4.34	<5.00	<1.11	3.82	154.4
	3	16.70	16.00	10.30	<2.82	5.96	<0.994	<3.33	<0.915	<1.18	5.44	<1.67	<2.12	3.49	3.37	<3.71	2.43	3.61	<2.68	<2.57	<4.98	<3.10	<5.00	<1.11	<3.37	67.3
	4	38.20	37.80	24.70	13.10	21.50	<0.994	8.15	<0.915	<1.18	8.58	4.25	4.01	15.10	11.60	5.83	<1.13	11.60	3.95	6.32	6.09	8.15	<5.00	<1.11	5.07	234.0
	5	42.50	50.00	31.90	17.40	28.10	<0.994	<3.33	2.44	<1.18	6.87	1.79	<2.12	<2.53	8.61	4.28	<1.13	6.99	<2.68	5.34	<4.98	<3.10	<5.00	<1.11	<3.37	206.2
	6	<5.40	<3.02	<1.93	<2.82	<1.71	<0.994	<3.33	<0.915	<1.18	4.97	<1.67	<2.12	<2.53	4.71	<3.71	<1.13	4.35	<2.68	<2.57	<4.98	4.03	<5.00	<1.11	<3.37	18.1
Subtidal	1	37.10	26.90	17.50	7.17	12.10	4.44	7.81	1.23	1.68	4.80	<1.67	<2.12	<2.53	<2.01	<3.71	<1.13	<2.67	<2.68	3.89	<4.98	3.96	<5.00	<1.11	<3.37	128.6
	2	40.70	29.80	18.80	7.79	9.21	<0.994	8.11	1.23	1.82	4.17	<1.67	<2.12	<2.53	<2.01	<3.71	<1.13	<2.67	<2.68	2.72	<4.98	3.34	<5.00	<1.11	<3.37	127.7
	3	19.50	15.10	8.55	3.69	6.89	<0.994	3.61	<0.915	<1.18	3.58	<1.67	<2.12	5.01	3.88	<3.71	<1.13	6.48	5.72	<2.57	<4.98	4.63	<5.00	<1.11	<3.37	86.6
	4	18.60	14.70	7.79	4.15	5.95	<0.994	3.99	<0.915	<1.18	2.08	<1.67	<2.12	<2.53	<2.01	<3.71	<1.13	<2.67	<2.68	<2.57	<4.98	<3.10	<5.00	<1.11	<3.37	57.3
	5	11.90	9.90	5.87	3.43	2.20	<0.994	<3.33	1.96	<1.18	2.15	<1.67	<2.12	<2.53	<2.01	<3.71	<1.13	<2.67	<2.68	<2.57	<4.98	<3.10	<5.00	<1.11	<3.37	37.4
	6	20.80	15.90	8.92	5.10	3.72	<0.994	4.15	<0.915	1.70	2.47	<1.67	<2.12	<2.53	<2.01	<3.71	<1.13	<2.67	<2.68	<2.57	<4.98	<3.10	<5.00	<1.11	<3.37	62.8
Intertidal	1	51.50	34.10	19.70	8.22	15.60	<0.994	13.40	<0.915	3.25	6.47	<1.67	<2.12	8.62	6.27	<3.71	<1.13	7.80	3.30	3.53	<4.98	4.06	<5.00	<1.11	<3.37	185.8
	4	86.70	59.20	35.50	21.20	12.90	<0.994	15.20	<0.915	<1.18	9.72	2.86	<2.12	23.40	19.50	9.39	<1.13	18.50	7.89	<2.57	8.90	11.10	7.58	2.87	7.55	360.0
	6	93.90	63.40	37.30	18.70	29.50	3.73	**20.70**	<0.915	6.66	11.10	3.33	<2.12	<2.53	<2.01	<3.71	<1.13	<2.67	<2.68	<2.57	7.01	15.50	7.18	<1.11	6.82	324.8
ERL		**160**	**70**				**44**	**16**		**19**	**240**	**85**		**600**	**665**	**261**	**384**				**430**			**63**		**4022**
ERM		**2100**	**670**				**640**	**500**		**540**	**1500**	**1100**		**5100**	**2600**	**1600**	**2800**				**1600**			**260**		**44792**

NAP = Naphthalene; 2-MN = 2-Methylnaphthalene; 1-MN = 1-Methylnaphthalene; BPN = Biphenyl; 2,6, DMN = 2,6 Dimethylnaphthalene; ACY = Acenaphthylene; ACE = Acenaphthene; 2,3,5, TMN = 2,3,5 Trimethylnaphthalene; FLO = Fluorene; PHN = Phenanthrene; ANT = Anthracene; 1-MPN = 1-Methylphenanthrene; FLU = Fluoranthene; PYR = Pyrene; BAA = Benzo(a)anthracene; CHR = Chrysene; BBF = Benzo(b)fluoranthene BKF = Benzo(k)fluoranthene; BEP = Benzo(e)pyrene; BAP = Benzo(a)pyrene; PER = Perylene; IDP = Indeno(1,2,3-cd)pyrene; DAHA = Dibenz(a,h)anthracene; BGHIP = Benzo(g,h,i)perylene

Table 4.5 Summary of concentrations (ng/g) of polychlorinated biphenyls (PCBs) found at sites in the Broad Creek and Okatee River sites. Total PCB concentrations, the cumulative ERL, and the cumulative ERM for each site are shown.

STATION		8 (PCB #)	18	28	52	44	118	153	105	128	180	195	206	209	29	50	104	66	87	77	154	188	138	126	187	201	170	101	Summed Concentration
Okatee River																													
Tidal Creek	1	<0.128	<0.150	<0.195	<0.068	<0.052	<0.067	<0.102	<0.122	<0.070	<0.107	<0.120	<0.098	<0.100	<0.100	<0.100	<0.100	<0.061	<0.100	<1.50	<0.100	<0.100	<0.178	<0.130	<0.048	<0.100	<0.157	<0.100	0.00
	2	<0.128	<0.150	<0.195	<0.068	<0.052	<0.067	<0.102	<0.122	<0.070	<0.107	<0.120	<0.098	<0.100	<0.100	<0.100	<0.100	<0.061	<0.100	<1.50	<0.100	<0.100	<0.178	<0.130	<0.048	<0.100	<0.157	<0.100	0.00
	3	<0.128	<0.150	<0.195	<0.068	<0.052	<0.067	<0.102	<0.122	<0.070	<0.107	<0.120	<0.098	<0.100	<0.100	<0.100	<0.100	<0.061	<0.100	<1.50	<0.100	<0.100	<0.178	<0.130	<0.048	<0.100	<0.157	<0.100	0.00
	4	<0.128	<0.150	<0.195	<0.068	<0.052	<0.067	<0.102	<0.122	<0.070	<0.107	<0.120	<0.098	<0.100	<0.100	<0.100	<0.100	<0.061	<0.100	<1.50	<0.100	<0.100	<0.178	<0.130	<0.048	<0.100	<0.157	<0.100	0.00
	5	<0.128	<0.150	<0.195	<0.068	<0.052	<0.067	<0.102	<0.122	<0.070	<0.107	<0.120	<0.098	<0.100	<0.100	<0.100	<0.100	<0.061	<0.100	<1.50	<0.100	<0.100	<0.178	<0.130	<0.048	<0.100	<0.157	<0.100	0.00
	6	<0.128	<0.150	<0.195	<0.068	<0.052	<0.067	<0.102	<0.122	<0.070	<0.107	<0.120	<0.098	<0.100	<0.100	<0.100	<0.100	<0.061	<0.100	<1.50	<0.100	<0.100	<0.178	<0.130	<0.048	<0.100	<0.157	<0.100	0.00
Subtidal	1	<0.128	<0.150	<0.195	<0.068	<0.052	<0.067	<0.102	<0.122	<0.070	<0.107	<0.120	<0.098	<0.100	<0.100	<0.100	<0.100	<0.061	<0.100	<1.50	<0.100	<0.100	<0.178	<0.130	<0.048	<0.100	<0.157	<0.100	0.00
	2	<0.128	<0.150	<0.195	<0.068	<0.052	<0.067	<0.102	<0.122	<0.070	<0.107	<0.120	<0.098	<0.100	<0.100	<0.100	<0.100	<0.061	<0.100	<1.50	<0.100	<0.100	<0.178	<0.130	<0.048	<0.100	<0.157	<0.100	0.00
	3	<0.128	<0.150	<0.195	<0.068	<0.052	<0.067	<0.102	<0.122	<0.070	<0.107	<0.120	<0.098	<0.100	<0.100	<0.100	<0.100	<0.061	<0.100	<1.50	<0.100	<0.100	<0.178	<0.130	<0.048	<0.100	<0.157	<0.100	0.00
	4	<0.128	<0.150	<0.195	<0.068	<0.052	<0.067	<0.102	<0.122	<0.070	<0.107	<0.120	<0.098	<0.100	<0.100	<0.100	<0.100	<0.061	<0.100	<1.50	<0.100	<0.100	<0.178	<0.130	<0.048	<0.100	<0.157	<0.100	0.00
	5	<0.128	<0.150	<0.195	<0.068	<0.052	<0.067	<0.102	<0.122	<0.070	<0.107	<0.120	<0.098	<0.100	<0.100	<0.100	<0.100	<0.061	<0.100	<1.50	<0.100	<0.100	<0.178	<0.130	<0.048	<0.100	<0.157	<0.100	0.00
	6	<0.128	<0.150	<0.195	<0.068	**0.07**	<0.067	<0.102	<0.122	<0.070	<0.107	<0.120	<0.098	<0.100	<0.100	<0.100	<0.100	<0.061	<0.100	<1.50	<0.100	<0.100	<0.178	<0.130	<0.048	<0.100	<0.157	<0.100	**0.07**
Intertidal	2	<0.128	<0.150	<0.195	<0.068	<0.052	<0.067	<0.102	<0.122	<0.070	<0.107	<0.120	<0.098	<0.100	<0.100	<0.100	<0.100	<0.061	<0.100	<1.50	<0.100	<0.100	<0.178	<0.130	<0.048	<0.100	<0.157	<0.100	0.00
	4	<0.128	<0.150	<0.195	<0.068	<0.052	<0.067	<0.102	<0.122	<0.070	<0.107	<0.120	<0.098	<0.100	<0.100	<0.100	<0.100	<0.061	<0.100	<1.50	<0.100	<0.100	<0.178	<0.130	<0.048	<0.100	<0.157	<0.100	0.00
	6	<0.128	<0.150	<0.195	<0.068	<0.052	<0.067	<0.102	<0.122	<0.070	<0.107	<0.120	<0.098	<0.100	<0.100	<0.100	<0.100	<0.061	<0.100	<1.50	<0.100	<0.100	<0.178	<0.130	<0.048	<0.100	<0.157	<0.100	0.00
Broad Creek																													
Tidal Creek	1	<0.128	<0.150	<0.195	<0.068	<0.052	<0.067	<0.102	<0.122	<0.070	<0.107	<0.120	<0.098	<0.100	<0.100	<0.100	<0.100	<0.061	<0.100	<1.50	<0.100	<0.100	<0.178	<0.130	<0.048	<0.100	<0.157	<0.100	0.00
	2	<0.128	<0.150	<0.195	<0.068	<0.052	<0.067	<0.102	<0.122	<0.070	<0.107	<0.120	<0.098	<0.100	<0.100	<0.100	<0.100	<0.061	<0.100	<1.50	<0.100	<0.100	<0.178	<0.130	<0.048	<0.100	<0.157	<0.100	0.00
	3	<0.128	<0.150	<0.195	<0.068	<0.052	<0.067	<0.102	<0.122	<0.070	<0.107	<0.120	<0.098	<0.100	<0.100	<0.100	<0.100	<0.061	<0.100	<1.50	<0.100	<0.100	<0.178	<0.130	<0.048	<0.100	<0.157	<0.100	0.00
	4	<0.128	<0.150	<0.195	<0.068	<0.052	<0.067	<0.102	<0.122	<0.070	<0.107	<0.120	<0.098	<0.100	<0.100	<0.100	<0.100	<0.061	<0.100	<1.50	<0.100	<0.100	<0.178	<0.130	<0.048	<0.100	<0.157	<0.100	0.00
	5	<0.128	<0.150	<0.195	<0.068	<0.052	<0.067	<0.102	<0.122	<0.070	<0.107	<0.120	<0.098	<0.100	<0.100	<0.100	<0.100	<0.061	<0.100	<1.50	<0.100	<0.100	<0.178	<0.130	<0.048	<0.100	<0.157	<0.100	**0.12**
	6	<0.128	<0.150	<0.195	<0.068	<0.052	<0.067	<0.102	<0.122	<0.070	<0.107	<0.120	<0.098	<0.100	**0.12**	<0.100	<0.100	<0.061	<0.100	<1.50	<0.100	<0.100	<0.178	<0.130	<0.048	<0.100	<0.157	<0.100	0.00
Subtidal	1	<0.128	<0.150	<0.195	<0.068	<0.052	<0.067	<0.102	<0.122	<0.070	<0.107	<0.120	<0.098	<0.100	<0.100	<0.100	<0.100	<0.061	<0.100	<1.50	<0.100	<0.100	<0.178	<0.130	<0.048	<0.100	<0.157	<0.100	0.00
	2	<0.128	<0.150	<0.195	<0.068	<0.052	<0.067	<0.102	<0.122	<0.070	<0.107	<0.120	<0.098	<0.100	<0.100	<0.100	<0.100	<0.061	<0.100	<1.50	<0.100	<0.100	<0.178	<0.130	<0.048	<0.100	<0.157	<0.100	0.00
	3	<0.128	<0.150	<0.195	<0.068	<0.052	<0.067	<0.102	<0.122	<0.070	<0.107	<0.120	<0.098	<0.100	<0.100	<0.100	<0.100	<0.061	<0.100	<1.50	<0.100	<0.100	<0.178	<0.130	<0.048	<0.100	<0.157	<0.100	0.00
	4	<0.128	<0.150	<0.195	<0.068	<0.052	<0.067	<0.102	<0.122	<0.070	<0.107	<0.120	<0.098	<0.100	<0.100	<0.100	<0.100	<0.061	<0.100	<1.50	<0.100	<0.100	<0.178	<0.130	<0.048	<0.100	<0.157	<0.100	0.00
	5	<0.128	<0.150	<0.195	<0.068	<0.052	<0.067	<0.102	<0.122	<0.070	<0.107	<0.120	<0.098	<0.100	<0.100	<0.100	<0.100	<0.061	<0.100	<1.50	<0.100	<0.100	<0.178	<0.130	<0.048	<0.100	<0.157	<0.100	0.00
	6	<0.128	<0.150	<0.195	<0.068	<0.052	<0.067	<0.102	<0.122	<0.070	<0.107	<0.120	<0.098	<0.100	<0.100	<0.100	<0.100	<0.061	<0.100	<1.50	<0.100	<0.100	<0.178	<0.130	<0.048	<0.100	<0.157	<0.100	0.00
Intertidal	1	<0.128	<0.150	<0.195	<0.068	<0.052	<0.067	<0.102	<0.122	<0.070	<0.107	<0.120	<0.098	<0.100	<0.100	<0.100	<0.100	<0.061	<0.100	<1.50	<0.100	<0.100	<0.178	<0.130	<0.048	<0.100	<0.157	<0.100	0.00
	4	<0.128	<0.150	<0.195	<0.068	<0.052	<0.067	<0.102	<0.122	<0.070	<0.107	<0.120	<0.098	<0.100	<0.100	<0.100	<0.100	<0.061	<0.100	<1.50	<0.100	<0.100	<0.178	<0.130	<0.048	<0.100	<0.157	<0.100	0.00
	6	<0.128	<0.150	<0.195	<0.068	<0.052	<0.067	<0.102	<0.122	<0.070	<0.107	<0.120	<0.098	<0.100	<0.100	<0.100	<0.100	<0.061	<0.100	<1.50	<0.100	<0.100	<0.178	<0.130	<0.048	<0.100	<0.157	<0.100	0.00

Table 4.6 Concentrations (ug/g) of pesticides found at sites in the Broad Creek and Okatee River sites. Corresponding ERL and ERM values are listed. All shaded cells exceeded one or more of the Sediment Quality Guidelines.

STATION		2,4'-DDD	2,4'-DDE	2,4'-DDT	4,4'-DDD	4,4'-DDE	4,4'-DDT	Total DDT	Aldrin	Cis-chlordane	Dieldrin	Lindane	Heptachlor	Heptachlor epoxide	Hexachloro-benzene	Mirex	Trans-nonachlor	Summed Concentration
Okatee River																		
Tidal Creek	1	<0.0610	<0.0580	<0.144	<0.243	<0.0330	<0.0160	0.00	<0.0130	<0.0820	<0.181	<0.0760	<0.0400	<0.102	<0.0620	0.17	<0.0940	0.17
	2	<0.0610	<0.0580	<0.144	<0.243	<0.0330	<0.0160	0.00	<0.0130	<0.0820	<0.181	<0.0760	<0.0400	<0.102	<0.0620	<0.157	<0.0940	0.00
	3	<0.0610	<0.0580	<0.144	<0.243	<0.0330	<0.0160	0.00	<0.0130	<0.0820	<0.181	<0.0760	<0.0400	<0.102	0.10	<0.157	<0.0940	0.10
	4	<0.0610	<0.0580	<0.144	<0.243	<0.0330	<0.0160	0.00	<0.0130	<0.0820	<0.181	<0.0760	<0.0400	<0.102	<0.0620	<0.157	<0.0940	0.00
	5	<0.0610	<0.0580	<0.144	<0.243	<0.0330	<0.0160	0.00	<0.0130	<0.0820	<0.181	<0.0760	<0.0400	<0.102	<0.0620	<0.157	<0.0940	0.00
	6	<0.0610	<0.0580	<0.144	<0.243	<0.0330	<0.0160	0.00	<0.0130	<0.0820	<0.181	<0.0760	<0.0400	<0.102	0.14	<0.157	<0.0940	0.14
Subtidal	1	<0.0610	<0.0580	<0.144	<0.243	<0.0330	<0.0160	0.00	<0.0130	<0.0820	<0.181	**0.99**	0.07	<0.102	<0.0620	<0.157	<0.0940	1.06
	2	<0.0610	<0.0580	<0.144	<0.243	<0.0330	<0.0160	0.00	<0.0130	<0.0820	<0.181	**0.49**	0.10	<0.102	<0.0620	<0.157	<0.0940	0.59
	3	<0.0610	<0.0580	<0.144	<0.243	<0.0330	<0.0160	0.00	<0.0130	<0.0820	<0.181	**0.35**	0.05	<0.102	<0.0620	<0.157	<0.0940	0.40
	4	<0.0610	<0.0580	<0.144	<0.243	<0.0330	<0.0160	0.00	<0.0130	<0.0820	<0.181	0.30	<0.0400	<0.102	<0.0620	<0.157	<0.0940	0.30
	5	<0.0610	<0.0580	<0.144	<0.243	<0.0330	<0.0160	0.00	<0.0130	<0.0820	<0.181	**0.39**	0.08	<0.102	<0.0620	<0.157	<0.0940	0.47
	6	<0.0610	<0.0580	<0.144	<0.243	<0.0330	<0.0160	0.00	<0.0130	<0.0820	<0.181	**0.36**	0.05	<0.102	0.07	<0.157	<0.0940	0.48
Intertidal	2	<0.0610	<0.0580	<0.144	<0.243	<0.0330	<0.0160	0.00	<0.0130	<0.0820	<0.181	<0.0760	1.19	<0.102	1.56	<0.157	<0.0940	2.75
	4	<0.0610	<0.0580	<0.144	<0.243	<0.0330	<0.0160	0.00	<0.0130	<0.0820	<0.181	<0.0760	0.28	<0.102	0.14	2.23	<0.0940	2.65
	6	<0.0610	<0.0580	<0.144	<0.243	<0.0330	<0.0160	0.00	<0.0130	<0.0820	<0.181	<0.0760	<0.0400	<0.102	<0.0620	<0.157	<0.0940	0.00
Broad Creek																		
Tidal Creek	1	<0.0610	<0.0580	<0.144	<0.243	<0.0330	<0.0160	0.00	0.97	<0.0820	<0.181	**1.36**	<0.0400	<0.102	<0.0620	<0.157	<0.0940	2.33
	2	<0.0610	<0.0580	<0.144	<0.243	<0.0330	<0.0160	0.00	0.34	<0.0820	<0.181	0.26	<0.0400	<0.102	<0.0620	<0.157	<0.0940	0.60
	3	<0.0610	<0.0580	<0.144	<0.243	<0.0330	<0.0160	0.00	<0.0130	<0.0820	<0.181	<0.0760	<0.0400	<0.102	<0.0620	<0.157	<0.0940	0.00
	4	<0.0610	<0.0580	<0.144	<0.243	<0.0330	<0.0160	0.00	<0.0130	<0.0820	<0.181	<0.0760	<0.0400	<0.102	0.10	<0.157	<0.0940	0.10
	5	<0.0610	<0.0580	<0.144	<0.243	<0.0330	<0.0160	0.00	<0.0130	<0.0820	<0.181	<0.0760	<0.0400	<0.102	<0.0620	<0.157	<0.0940	0.00
	6	<0.0610	<0.0580	<0.144	<0.243	<0.0330	<0.0160	0.00	<0.0130	<0.0820	<0.181	<0.0760	<0.0400	<0.102	<0.0620	<0.157	<0.0940	0.00
Subtidal	1	<0.0610	<0.0580	<0.144	<0.243	<0.0330	<0.0160	0.00	0.05	<0.0820	<0.181	<0.0760	<0.0400	<0.102	<0.0620	<0.157	<0.0940	0.05
	2	<0.0610	<0.0580	<0.144	<0.243	<0.0330	<0.0160	0.00	<0.0130	<0.0820	<0.181	<0.0760	<0.0400	<0.102	<0.0620	<0.157	<0.0940	0.00
	3	<0.0610	<0.0580	<0.144	<0.243	<0.0330	<0.0160	0.00	<0.0130	<0.0820	<0.181	<0.0760	0.07	<0.102	<0.0620	<0.157	<0.0940	0.07
	4	<0.0610	<0.0580	<0.144	<0.243	<0.0330	<0.0160	0.00	<0.0130	<0.0820	<0.181	<0.0760	<0.0400	<0.102	<0.0620	<0.157	<0.0940	0.00
	5	<0.0610	<0.0580	<0.144	<0.243	<0.0330	<0.0160	0.00	<0.0130	<0.0820	<0.181	**0.68**	0.05	<0.102	<0.0620	<0.157	<0.0940	0.72
	6	<0.0610	<0.0580	<0.144	<0.243	<0.0330	<0.0160	0.00	<0.0130	<0.0820	<0.181	<0.0760	<0.0400	<0.102	<0.0620	<0.157	<0.0940	0.00
Intertidal	1	<0.0610	<0.0580	<0.144	<0.243	<0.0330	<0.0160	0.00	<0.0130	<0.0820	<0.181	<0.0760	<0.0400	<0.102	0.07	<0.157	<0.0940	0.07
	4	<0.0610	<0.0580	<0.144	<0.243	<0.0330	<0.0160	0.00	<0.0130	<0.0820	<0.181	<0.0760	0.08	<0.102	<0.0620	<0.157	<0.0940	0.08
	6	<0.0610	<0.0580	<0.144	<0.243	<0.0330	<0.0160	0.00	0.15	<0.0820	**0.19**	**2.43**	<0.0400	<0.102	<0.0620	<0.157	<0.0940	2.78
ERL								**1.58**			**0.02**							
ERM								**46.10**			**8.00**							
TEL												**0.32**						
PEL												**0.99**						

Table 4.7 Maximum sediment concentrations found in the Broad Creek and Okatee River for the contaminants analyzed in this study and those found in a similar study for the relatively pristine ACE Basin. The % of sites exceeding the SQGs for an analyte are listed as (%>ERL/TEL, %>ERM/PEL). bdl = below detection limits. * only cis chlordane measured.

Contaminant	Broad	Okatee	ACE
Metals			
Arsenic	13.7 (27%, 0%)	14.3 (33%, 0%)	14.2
Cadmium	0.0782	0.386	0.33
Chromium	65.6	75.7	60.8
Copper	17.1	11.4	8.57
Lead	19.9	22.8	21
Mercury	0.0863	0.104	3.3
Nickel	18	19.4	16.9
Silver	<0.0211	<0.0211	0.02
Zinc	70.6	67.8	57.83
Pesticides			
p,p'-DDE	<0.0330	<0.0330	0.464
DDE (o,p & p,p)	<0.0580	<0.0580	4.64
DDT (o,p & p,p)	<0.144	<0.144	0.952
DDD (o,p & p,p)	<0.243	<0.243	1.04
Total DDT (all 6 isomers)	bdl	bdl	1.04
Chlordane**	<0.0820	<0.0820	<0.082
Dieldrin	0.192 (7%, 0%)	<0.181	<0.181
Gamma BHC (lindane)	2.43 (20%, 7%)	0.99 (33%, 7%)	0.161
PAHs			
2-methylnaphthalene	63.4	66.9	78.9
Acenaphthene	20.7 (7%, 0%)	16	15.9
Acenaphthylene	4.44	3.75	0.5
Anthracene	4.25	3.37	14.8
Benzo(a)anthracene	9.39	7.68	23.8
Benzo(a)pyrene	10.5	7.13	29.8
Chrysene	2.43	16.2	34
Dibenzo(a,h)anthracene	2.87	<1.11	3.5
Fluoranthene	23.4	16.3	16.5
Fluorene	6.66	2.88	6.8
Naphthalene	93.9	96.4	88.9
Phenanthrene	11.1	16.5	21.1
Pyrene	19.5	11.2	67.8
Total PAH	360	286.5	299.0
PCBs			
Total PCBs	0.12	0.07	<1.499

Table 4.8 Cumulative ERM/PEL and cumulative ERM/PEL Quotients for the analyte classes examined.

Station		ERM/PEL Quotient				
		Metals	PAHs	PCBs	Pesticides	All Analytes
Okatee River						
Tidal Creek	1	0.061	0.005	0.000	0.000	0.023
	2	0.063	0.006	0.000	0.000	0.025
	3	0.041	0.005	0.000	0.000	0.017
	4	0.137	0.003	0.000	0.000	0.049
	5	0.078	0.007	0.000	0.000	0.031
	6	0.128	0.012	0.000	0.000	0.050
River Subtidal	1	0.009	0.004	0.000	0.332	0.044
	2	0.004	0.002	0.000	0.164	0.021
	3	0.005	0.002	0.000	0.116	0.016
	4	0.002	0.003	0.000	0.100	0.014
	5	0.063	0.006	0.000	0.133	0.040
	6	0.002	0.003	0.000	0.122	0.016
River Intertidal	2	0.112	0.004	0.000	0.000	0.041
	4	0.129	0.013	0.000	0.000	0.051
	6	0.109	0.010	0.000	0.000	0.043
Broad Creek						
Tidal Creek	1	0.066	0.005	0.000	0.456	0.078
	2	0.058	0.006	0.000	0.086	0.033
	3	0.033	0.003	0.000	0.000	0.013
	4	0.084	0.009	0.000	0.000	0.033
	5	0.074	0.008	0.000	0.000	0.030
	6	0.030	0.000	0.000	0.000	0.011
River Subtidal	1	0.027	0.007	0.000	0.000	0.013
	2	0.023	0.007	0.000	0.000	0.011
	3	0.021	0.003	0.000	0.000	0.009
	4	0.008	0.003	0.000	0.000	0.004
	5	0.009	0.002	0.000	0.228	0.030
	6	0.011	0.004	0.000	0.000	0.006
River Intertidal	1	0.052	0.009	0.000	0.000	0.023
	4	0.129	0.016	0.000	0.000	0.052
	6	0.119	0.016	0.001	0.827	0.146

Table 4.9 Mean EC_{50} values for Microtox. Shaded cells indicate sites that were significantly different from regional standards.

STATION		Mean EC_{50}	St. Dev.
Okatee River			
Tidal Creek	1	0.1345	0.0109
	2	0.0878	0.0098
	3	0.4871	0.0511
	4	0.0666	0.0035
	5	0.0947	0.0050
	6	0.0792	0.0101
River Subtidal	1	1.4841	0.1290
	2	18.5737	0.0000
	3	1.4025	0.3467
	4	3.6773	0.3473
	5	0.0624	0.0069
	6	18.9537	0.0000
River Intertidal	2	0.6712	0.1146
	4	0.1163	0.0226
	6	0.8829	0.2069
Broad Creek			
Tidal Creek	1	0.0778	0.0040
	2	0.1652	0.0066
	3	0.3819	0.0994
	4	0.0578	0.0064
	5	0.0371	0.0138
	6	0.1099	0.0155
River Subtidal	1	0.1745	0.0108
	2	0.3435	0.0397
	3	0.1767	0.0270
	4	8.6377	4.1733
	5	17.8586	0.0000
	6	0.6030	0.1752
River Intertidal	1	0.2197	0.0243
	4	0.0382	0.0065
	6	0.0312	0.0099

Table 4.10 Results of Broad Creek and Okatee River statistical comparsions of the sediment quality parameters measured. Shaded cells indicate statistical significance at α=0.05.

Comparison			Spearman Ranked Correlation Results coeffiecent of correlation	p value
Sediment Chemistry (cumulative ERM)	vs.	Oyster Fetilization Rate	-0.3798	0.0385
		Oyster Development Rate	0.142	0.4493
		Average Growth of Clams	-0.51368	0.00387
		Microtox EC_{50}	-0.3741	0.04173
		Water Quality	-0.0563	0.76533
		Arsenic	0.64	0.03
		Lindane	0.28	0.13
Oyster Fertilization	vs.	Oyster Development Rate	0.22	0.2393
		Average Growth of Clams	0.187	0.3203
		Microtox EC_{50}	0.187	0.3203
		Water Quality	0.229	0.2213
		Arsenic	-0.351	0.0574
		Lindane	-0.0618	0.744
Oyster Development Rate	vs.	Average Growth of Clams	0.00934	0.9587
		Microtox EC_{50}	0.242	0.197
		Water Quality	-0.3	0.1063
		Arsenic	-0.0374	0.842
		Lindane	0.215	0.251
Average Growth of Clams	vs.	Microtox EC_{50}	0.3341	0.7083
		Water Quality	-0.133	0.4793
		Arsenic	-0.525	0.003
		Lindane	0.107	0.57
Microtox EC_{50}	vs.	Water Quality	-0.213	0.2563
		Arsenic	-0.58	0.003
		Lindane	0.232	0.215
Lindane	vs.	Arsenic	-0.4491	0.013

Table 4.11 Results from clam growth bioassays showing average growth per day in mg. Shaded cells indicate growth less than 80% of controls and significantly different ($p<0.05$).

STATION		AVG. GROWTH PER DAY (mg)
Okatee River		
Tidal Creek	1	-3.586
	2	-0.927
	3	1.193
	4	-0.251
	5	-1.470
	6	9.040
River Subtidal	1	10.428
	2	9.953
	3	5.208
	4	4.428
	5	9.415
	6	8.289
River Intertidal	2	-0.561
	4	1.918
	6	-1.092
Broad Creek		
Tidal Creek	1	-2.028
	2	-2.301
	3	11.455
	4	-2.871
	5	4.886
	6	17.293
River Subtidal	1	0.270
	2	11.153
	3	10.543
	4	11.507
	5	13.411
	6	12.397
River Intertidal	1	7.170
	4	4.393
	6	3.413

Table 4.12 Fertilization rates for oyster gametes exposed to sediment elutriates. Data are expressed as mean % sediment controls (n=4 replicates); standard deviations are shown in parenthese. NA indicates no data available or not applicable.
*=significantly different from control sediments.

Sediment ID	System	Region	Strata	20% Elutriate	50% Elutriate	100% Elutriate
Controls - Set 1	Folly	NA	NA	100.00 (0.87)	100.00 (0.65)	100.00 (0.75)
Controls - Set 2	Folly	NA	NA	NA	100.00 (2.59)	100.00 (0.77)
Controls - Set 3	Folly	NA	NA	100.00 (1.52)	100.00 (0.53)	100.00 (1.15)
OBS1	Okatee	River	1	NA	101.96 (1.71)	100.47 (1.19)
OBS2	Okatee	River	2	NA	101.21 (2.03)	100.95 (1.90)
OBS3	Okatee	River	3	NA	100.44 (0.45)	100.28 (1.84)
OBS4	Okatee	River	4	NA	101.06 (0.43)	100.66 (1.23)
OBS5	Okatee	River	5	99.49 (0.87)	99.88 (0.29)	99.19 (0.29)
OBS6	Okatee	River	6	99.38 (0.62)	98.82 (0.81)	98.21 (0.32)
OBI2	Okatee	Intertidal	2	99.49 (0.96)	98.10 (2.78)	97.75 (0.90)
OBI4	Okatee	Intertidal	4	99.27 (0.55)	98.36 (0.65)	97.94 (0.72)
OBI6	Okatee	Intertidal	6	99.88 (0.48)	98.38 (1.69)	98.18 (1.06)
OBT1	Okatee	Tidal Creek	1	97.55 (1.76)	100.65 (1.80)	98.20 (1.11)
OBT2	Okatee	Tidal Creek	2	102.52 (0.48)	100.92 (1.45)	100.43 (2.30)
OBT3	Okatee	Tidal Creek	3	102.33 (1.78)	100.92 (1.14)	101.15 (1.26)
OBT4	Okatee	Tidal Creek	4	97.93 (0.95)	99.09 (2.07)	97.17 (0.77)
OBT5	Okatee	Tidal Creek	5	100.53 (1.93)	99.05 (1.40)	100.55 (0.70)
OBT6	Okatee	Tidal Creek	6	97.57 (1.83)	99.07 (1.39)	98.57 (1.63)
BBS1	Broad	River	1	NA	98.11 (4.70)	98.59 (1.49)
BBS2	Broad	River	2	NA	101.71 (1.80)	99.81 (1.71)
BBS3	Broad	River	3	99.13 (0.95)	97.98 (2.03)	97.23 (0.65)
BBS4	Broad	River	4	NA	99.35 (1.23)	99.23 (0.65)
BBS5	Broad	River	5	98.99 (1.57)	98.65 (0.68)	98.43 (1.71)
BBS6	Broad	River	6	NA	101.86 (0.69)	99.18 (1.65)
BBI1	Broad	Intertidal	1	NA	99.11 (2.85)	100.99 (1.36)
BBI4	Broad	Intertidal	4	NA	99.73 (1.03)	92.12 (13.23)
BBI6	Broad	Intertidal	6	98.86 (0.76)	98.48 (1.05)	98.17 (1.34)
BBT1	Broad	Tidal Creek	1	97.92 (2.13)	99.73 (1.43)	97.42 (1.29)
BBT2	Broad	Tidal Creek	2	95.56 (1.40)	99.49 (1.51)	**85.17 (2.18)** [A]
BBT3	Broad	Tidal Creek	3	97.92 (1.60)	97.78 (1.95)	100.14 (1.12)
BBT4	Broad	Tidal Creek	4	100.25 (0.68)	101.97 (1.12)	101.05 (0.75)
BBT5	Broad	Tidal Creek	5	99.63 (1.66)	100.49 (0.68)	100.89 (1.30)
BBT6	Broad	Tidal Creek	6	101.57 (0.75)	101.51 (0.80)	100.25 (0.66)

Table 4.13 Development rates for oyster gametes exposed to sediment elutriates. Data are expressed as mean % sediment controls (n=4 replicates); standard deviations are shown in parentheses. NA indicates no data available or not applicable.

Sediment ID	System	Region	Strata	20% Elutriate	50% Elutriate	100% Elutriate
Controls - Set 1	Folly	NA	NA	100.00 (19.61)	100.00 (6.23)	100.00 (3.73)
Controls - Set 2	Folly	NA	NA	NA	100.00 (28.20)	100.00 (23.39)
Controls - Set 3	Folly	NA	NA	100.00 (15.93)	100.00 (9.72)	100.00 (11.13)
OBS1	Okatee	River	1	NA	84.52 (14.03)	110.78 (6.62)
OBS2	Okatee	River	2	NA	117.86 (11.80)	126.57 (10.93)
OBS3	Okatee	River	3	NA	111.90 (12.28)	108.27 (3.17)
OBS4	Okatee	River	4	NA	97.62 (8.85)	104.01 (13.78)
OBS5	Okatee	River	5	120.42 (20.07)	142.64 (8.59)	118.63 (13.53)
OBS6	Okatee	River	6	125.82 (28.81)	132.09 (12.08)	126.77 (21.29)
OBI2	Okatee	Intertidal	2	106.81 (17.27)	101.32 (20.85)	110.49 (20.97)
OBI4	Okatee	Intertidal	4	124.65 (11.56)	115.38 (15.35)	126.77 (25.13)
OBI6	Okatee	Intertidal	6	109.15 (13.64)	112.97 (17.11)	115.42 (14.12)
OBT1	Okatee	Tidal Creek	1	108.46 (18.53)	108.87 (9.24)	103.56 (11.77)
OBT2	Okatee	Tidal Creek	2	112.90 (21.20)	112.70 (18.83)	115.45 (17.81)
OBT3	Okatee	Tidal Creek	3	114.38 (13.80)	103.83 (5.64)	116.63 (6.38)
OBT4	Okatee	Tidal Creek	4	108.25 (8.90)	117.74 (8.14)	101.39 (17.63)
OBT5	Okatee	Tidal Creek	5	100.42 (13.45)	94.15 (11.18)	123.76 (9.09)
OBT6	Okatee	Tidal Creek	6	120.08 (14.60)	107.46 (9.16)	111.29 (11.93)
BBS1	Broad	River	1	NA	111.43 (3.89)	98.25 (25.51)
BBS2	Broad	River	2	NA	129.76 (9.82)	141.35 (20.35)
BBS3	Broad	River	3	96.24 (7.99)	90.11 (16.99)	94.86 (18.82)
BBS4	Broad	River	4	NA	100.48 (8.61)	84.46 (12.95)
BBS5	Broad	River	5	110.80 (5.14)	111.21 (9.96)	105.14 (11.35)
BBS6	Broad	River	6	NA	96.90 (9.54)	90.23 (5.24)
BBI1	Broad	Intertidal	1	NA	100.00 (17.75)	103.26 (10.92)
BBI4	Broad	Intertidal	4	NA	70.24 (17.77)	83.17 (8.99)
BBI6	Broad	Intertidal	6	95.54 (21.85)	122.64 (104.93)	104.93 (19.89)
BBT1	Broad	Tidal Creek	1	114.38 (15.96)	111.29 (4.01)	111.68 (10.53)
BBT2	Broad	Tidal Creek	2	118.18 (9.30)	110.08 (13.58)	103.96 (6.32)
BBT3	Broad	Tidal Creek	3	118.18 (5.37)	111.29 (19.28)	116.24 (6.73)
BBT4	Broad	Tidal Creek	4	109.94 (10.19)	90.32 (12.44)	98.02 (7.69)
BBT5	Broad	Tidal Creek	5	106.55 (2.07)	107.26 (7.42)	105.94 (6.45)
BBT6	Broad	Tidal Creek	6	112.26 (9.70)	110.48 (20.19)	105.35 (8.89)

Table 4.14 Summary of sediment chemistry findings. For Microtox, T = significant reduction in respiration. For Clam Bioassays, T=toxicity (reduced clam growth) and T*=toxicity (reduced clam growth) possibly due to ammonia. For oyster bioassays, PT = partial toxicity. G = Good, M = marginally degraded and D = degraded.

Okatee River	**Station**	**Contaminants**	**Microtox**	**Clam**	**Oyster**	**ERM/PEL Q**	**Overall Sediment Quality**
Tidal Creek	1		T	T*		G	M
	2		T	T*		M	M
	3			T*		G	G
	4	As	T	T*		M	M
	5		T	T*		M	M
	6	As	T	T		M	D
River	1	**Lindane**				M	D
	2	Lindane				G	G
	3	Lindane		T		G	M
	4			T		G	G
	5	Lindane	T			M	M
	6	Lindane				G	G
Intertidal	2	As		T		M	M
	4	As		T		M	M
	6	As		T		M	M
Broad Creek							
Tidal Creek	1	**Lindane**	T	T*		D	D
	2		T	T*	PT	M	M
	3		T	T		G	D
	4	As	T	T*		M	M
	5	As	T	T		M	D
	6		T			G	M
River	1			T		G	G
	2					G	G
	3		T			G	G
	4		T			G	G
	5	Lindane	T			M	M
	6					G	G
Intertidal	1					G	G
	4	As	T	T		M	D
	6	As, Acenapthene, **Lindane**, Dieldrin	T	T		D	D

Classification scheme for overall ranking:

Good: At most, one ERL/TEL exceedance, **or** one toxicity result

Marginal: At least two indications of potential toxicity (ERL/TEL exceedances or marginal ERM/PELQ and, at most one positive toxicity test result (not related to high ammonia))

Degraded: One or more ERM/PEL exceedances, **or** at least one ERL/PEL exceedance and at least two positive toxicity test results (not related to high ammonia)